MODERN PLYWOOD

THOMAS D. PERRY

Authority on Woodworking

Pioneer in Plywood Development

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"Introduces even the experienced user to new possibilities."

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"A comprehensive book intelligible to the average woodworker."

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"Treatment is authoritative, presentation is logical and the text is readable."

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"Manufacture of veneers and plywood is covered in detail and industrial uses are described."

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This book suggests new and less expensive methods of manufacture and construction; new products. Recent striking advances in the manufacture of Plywood have so broadened its use that a sound knowledge of this versatile material is invaluable to designers and executives in industries of all types.

Both manufacture and utilization are for the first time treated comprehensively and with authority in this, the only book published on Plywood in more than a decade. Techniques developed since the use of synthetic resin adhesives are fully and effectively described and brief, clear material is given on the earlier method of manufacture, which still has a definite place in the industry.

Valuably suggestive, the hundreds of vital uses of Plywood are conveniently classified into types such as Aircraft Construction, Furniture and the Allied Industries, Boats and Ships, Containers and Shooks, Construction and Building, Sporting Goods, Trunks and Baggage, etc. This material is indispensable to both new and established users of Plywood.

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THOMAS D. PERRY

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FOREWORD

When an epochal development occurs in a major industry, it calls for a realignment of factory procedure. It also demands a revision of the literature of the industry, so that the manufacturer, the consumer and the engineer can take advantage of the new technique.

The last five years have witnessed the development and growth of resin adhesives to such a point that they are becoming an important factor in the utilization of plywood. This evolutionary process easily ranks as the most progressive step taken by the plywood industry in the last quarter of a century.

It is essential that these facts be made available through the medium of such a book as *Modern Plywood.* It has been the aim of the author to delineate, clearly and briefly, the earlier technique, which still has a definite place in the industry. It is equally necessary to describe and compare the later technique, which is encouraging the extension of the use of plywood into many fields where its use formerly had been restricted. The new technique also is opening up new fields for plywood, where the durability characteristics of resin-bonded plywood add distinct advantages to the many attributes which have made plywood increasingly useful in a wide range of wood products.

Such a venture cannot hope to cover completely the resin-adhesive field, since investigations and developments are still in progress. However, it is hoped that this book may furnish a foundation on which readers may build a better understanding of the service that improved plywood can render in our advancing industrial progress.

THOMAS D. PERRY

Moorestown, New Jersey

ACKNOWLEDGMENTS

One of the essential factors in the compilation of a book of this type is a proper recognition of the existing literature of the industry. While formal publications in this field are limited, there is a large amount of information in current periodicals, particularly on the rapidly growing technique of resin adhesives. Reference to the bibliography at the back of the book confirms this fact.

The author has drawn generously from many of these and acknowledges with appreciation the permission to use copyright and other material from the following:

American Society of Mechanical Engineers
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The co-operation of the Resinous Products & Chemical Co., Inc., and many of its staff is acknowledged gratefully, together with its permission to reproduce any of its published and copyrighted material.

Appreciation is also extended to many other authorities, too numerous to mention, but without whose help this project would be less complete. Wherever possible, the source of original photographs and drawings has been given proper credit.

Many of the processes and products herein are patented and interested readers should investigate adequately.

The personal co-operation of many long-time friends in the industry has been most gratifying and has afforded needed encouragement in the completion of a difficult task. It is only by such wholehearted co-operation on the part of the many whose activities have contributed to plywood progress, that this book can hope to be a success.

THOMAS D. PERRY

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INTRODUCTION

The rise of plywood is one of the most dramatic and significant chapters in the history of the American Lumber and Timber Products Industries. Little more than a novel "idea" during World War I, it has now become an industrial giant. Two or three decades ago plywood was largely an experimental material and with a narrow range of specialty uses. Today it is a standard material for wide and increasing ranges of construction and industrial uses. American plywood is finding extensive foreign markets notwithstanding the wartime obstacles to international trade.

Plywood has established itself as a major material for wall covering and for surface uses. In its larger sizes and dimensions it is being used more widely in heavy construction. It is supplementing steel in boat building, the scarcer metals in aircraft, and ceramics and plastics in many important uses. Plywoods and laminated wood structures of wide variety are still in their early stages of development. They hold great future promise for the lumber industry and for the users of lumber and timber products.

The author is well qualified to present the most significant and most useful facts regarding the manufacture, distribution and uses of plywood. He is an outstanding member of his profession. A graduate of the Massachusetts Institute of Technology in Mechanical Engineering, he started his long career in the woodworking industries with the Grand Rapids Veneer Works. He was one of the organizers of the Wood Industries Division of the American Society of Mechanical Engineers and has for many years been one of the leaders in its activities. He has been associated with outstanding manufacturers of American plywoods. He was for some years the President of the Plywood Manufacturers Association, and during the entire period of its activity was an active member of the National Committee on Wood Utilization, appointed in 1926 by the then Secretary of Commerce, Mr. Herbert C. Hoover.

The author has published many technical papers and reports on wood uses, on woodworking and on plywoods. He has delivered

many lectures before colleges, industrial associations and technical societies. Outstanding among his contributions to the literature of the woodworking industries are:

Veneers and Plywood, 1926, of which he was the technical editor; the Wood Products Section of *National Encyclopedia,* 1932; and the section on Woodworking in Kent's *Mechanical Engineers' Handbook,* 1938, of which he was the editor.

In the field of mechanical engineering and woodworking he is widely recognized. His authorship of *Modern Plywood* will be acceptable alike to engineers and to the manufacturers and users of plywood.

WILSON COMPTON

National Lumber Manufacturers Association
Washington, D. C.

MODERN PLYWOOD

GLOSSARY OF TRADE TERMS USED IN THE PLYWOOD INDUSTRY

The brief definitions in this glossary are either general terms that have acquired a special meaning, or relatively new phrases that have been recognized recently in the plywood industry.

For further description the reader may consult the index references and find more complete details in the text.

A

adhesive—A broader term than **glue,** which ordinarily does not include the recently developed resin adhesives. Adhesion is defined as the "sticking together of substances in contact." Cf. **resin** and **glue.**

aging of plywood—A term used to designate the period, usually a matter of days, after the initial adhesive grip has become effective, and until the joint has developed approximately its maximum strength, and is suitable for testing.

albumin, blood—See **glue.**

all-veneer construction—Plywood without lumber cores, more frequently multi-ply for strength requirements, often 7-ply or 9-ply, to equal the thickness of conventional lumber-core plywood. The maximum thickness of any single sheet of veneer seldom exceeds ¼ inch.

animal glue—See **glue.**

assembly—The collection of and placing together in proper order of the layers of veneer, lumber and/or other materials, with the adhesive, ready to be pressed and bonded into plywood. **Assembly time** usually refers to the elapsed time after the glue is spread and until the pressure becomes effective. See **lay-up.**

B

back—Usually the rear or unexposed surface of a plywood sheet that requires normal strength, but does not demand any selection for appearance. Should be reasonably equivalent to the **face** (q.v.) in thickness and strength.

balanced construction—Plywood which has an equal amount of wood in each grain direction, an odd number of plies, and is symmetrical on both sides of its center line.

bale, or bundle—A bundle or package of freshly glued (cold-pressed) plywood, held together by **clamp irons** (q.v.), after removal from the cold press. The bale is kept under pressure until initial adhesion is accomplished.

Cf.=compare with.
Q. v.=which see (quod vide).

banding, or railing—A strip of wood, of any specified kind, extending around one or more sides of a lumber or all-veneer core, usually with a lengthwise grain. This banding facilitates shaping the edges, or may be finished square to conceal the objectionable appearance of the pieces of the core and the crossbands. Designated thus: B 1 S 2 E = banded one side and two ends.

bands, cross—See **crossbanding.**

bark—The natural exterior, or rough skin, of the wood log.

bastard sawn—Lumber or veneer, usually hardwood, in which the annual growth rings make angles of 30° to 60° with the surface of the piece.

bird's-eye—A growth due to local sharp depressions in the annual rings, accompanied by considerable distortion. Once the depressions are formed, succeeding growth rings follow the same contour for many years. In plain-sawn lumber and rotary-cut veneer, these depressions are cut crosswise and show a series of circlets, portions of annual rings, suggesting somewhat remotely a bird's eye.

blemish, same as **defect** (q. v.)—Usually applies to minor defects.

blister, (gluing error)—A spot or area where the veneer does not adhere and bulges like a blister. It may be caused by lack of of glue or adhesive or inadequate pressure. In **hot pressing** it may be caused by a pocket of steam, which often ruptures the veneer.

blister figure—This consists of seeming knoll-like elevations in the wood. It is due to an uneven contour, and not to blisters or pockets in the wood as the name might indicate. Also called **quilted figure.**

block—That section of the log, usually 4 to 10 feet long, from which the sheets of veneer are cut.

blood glue—See **glue, albumin.**

bole—The trunk of the tree.

bond—The grip of the adhesive on the wood, at the line of its application. Used especially with heat-reactive resins. Cf. setting in glues.

book matching—See **matching.**

brashness—A condition of wood characterized by low resistance to shock and by an abrupt failure across the grain without splintering.

broken stripe—A modification of **ribbon stripe figure** (q. v.), due to undulations in the annual growth rings of the tree, which produce changes in the angles of the fibres.

bulked down—See **solid piled.**

bundle—See **bale.**

burl—A type of figure produced by cutting through the wart-like protuberances that grow on trees of certain species. They contain the dark pith centers of a large number of undeveloped buds.

butt joint—See **joint.**

butt matching—See **matching.**

butt veneer—See **stump veneer.**

C

casein—See glue.

cassava—See **glue.**

cat eyes—Term used to describe small **pin knots** (q. v.), less than ¼ inch in diameter.

catalyst—A hardener for resin adhesives. A reagent that accelerates a chemical reaction, with or without heat. In the case of resinous adhesives, it accelerates setting or hardening.

caul, aluminum—Used in hot pressing, approximately 1/16 inch thick and the size of the hot-press platens. Plywood assemblies are inserted between pairs of cauls, to facilitate loading the press, and to protect plywood faces from contact with the steel plates of the hot press. Earlier, plywood cauls were used in hot pressing, 1/16 to ¼ inch thick. They were replaced by aluminum for quicker work and better durability.

caul, plywood—Used in cold pressing with conventional glues, to assure undamaged faces and to prevent transmission of defects to adjacent assemblies. Usually ¼ to ⅜ inch thick with waxed surfaces, to avoid adhesion. See also above.

cement—A term sometimes used for **liquid glue,** (q. v.)

centers—See **cores.**

centers, banded—See **cores,** banded.

chain figure—A succession of short cross markings of uniform character, remotely suggesting the cross links of a chain.

checks—Small hair-line splits running parallel to the grain of the wood, caused chiefly by stresses produced in seasoning.

clamp irons—The pressure maintenance equipment, which includes the "I" beams or double channel irons, together with R. & L. clamp screws or turnbuckle rods, to hold bales under pressure after cold gluing.

clipper—The shearing machine used to dimension green or dry veneers.

compregnated wood (Compreg.) (Pregwood) (Jicwood)—A consolidation of the terms, compressed-impregnated wood, refer-

ring usually to an assembly of layers of veneer impregnated with a liquid resin and bonded under very high pressures. More commonly, but not always, the veneer layers have parallel grain, i.e., laminated wood construction. **Jicwood** is the term used in England.

condensation—A more correct chemical term for **polymerization** (q. v.), as applied to resin adhesives.

construction, all-veneer—See **all-veneer construction.**

construction, balanced—See **balanced construction.**

construction, laminated—See **laminated wood.**

construction, lumber-core—See **lumber-core construction.**

conveyor—A device, usually consisting of a series of belts or rollers, which transports material from one department to another, or from one machine to another, or serves to load a machine, like a veneer drier. Also describes overhead chain and trolley equipment to transfer heavy, clamped bales from the cold press to the storage room.

cooking vat—An open pit, containing water heated by steam, to cook or stew the blocks or flitches, for smooth knife cutting on lathes and slicers.

cores, or centers—A term usually applied to the central layer of plywood, which in lumber-core construction (q. v.) is the principal strength factor. It is also applied to veneer cores. The term is sometimes used in the Pacific Northwest to designate the layer that is spread with glue, which agrees with the above in 3-ply, but is inconsistent when applied to 5-ply. **Core** also may refer to the remaining part of the log, too small to be cut into veneer on a **lathe.**

cores, banded—Lumber or veneer cores with banding or railing on one or more edges. Cf. **banding.**

cross fire—A distortion of the wood fibres of the tree which, when cut in a radial direction, produces figures and highlights similar to a corrugated surface. Also called **cross figure.**

crossbanding—The transverse veneer layers that distinguish plywood from **laminated wood** (q. v.). Their presence counteracts the tendency of wood to split, as well as to shrink and swell. In standard 5-ply construction it is the layer between the face and the core, and between the back and the core, sometimes called face crossing and back crossing respectively.

crossings—See **crossbanding.**

crotch veneer—Veneers cut from the side of a crotch or fork of large branches, usually displaying a curly and flowery figure.

cure of resin—See **polymerization.**

D

dead piled—See **solid piled.**

defect—Any fault, or imperfection, in the veneer or completed plywood, that may lower its strength, durability, attractiveness or utility value. Minor defects are often called **blemishes,** q. v.

defects, open—Checks, splits, open joints, cracks, loose knots, worm holes, or other defects interrupting the smooth continuity of the plywood surface.

diamond matching—See **matching.**

doors, plywood—**Panel doors** are those in which the stile and rail framework is thicker than the more central panels. **Flush** or slab doors are of uniform thickness with flat surfaces. Cores may be solid, of edge and end glued lumber, or hollow.

doze, or dote—A form of decay, characterized by a dull and lifeless appearance of the wood, accompanied by a lack of strength and a softening of the wood substance.

drier—A kiln or chamber or machine, through which the green or fresh veneer sheets are passed, to remove the excess moisture.

E

edge joint—See **joint.**

endy veneer—A colloquial term applied to veneer where the wood fibre (or cell) is cut at a substantial angle to the surface of the veneer, as in crotches, stumps, or adjacent to knots. Endy wood is usually darker in color, producing pleasing contrasts, is quite fragile, and permits the penetration of glue or the absorption of finishing materials.

equilibrium moisture content—The moisture content at which wood neither gains nor loses moisture when surrounded by air at a given relative humidity and temperature.

extender—An additional substance, sometimes combined in adhesive resins, to provide body, or reduce costs, or impart some other desirable quality. Some extenders, like grain flours, clay or wood flours, may be relatively inert. Soluble dried blood can be used under certain conditions, both as an extender and as a supplementary adhesive. Limited amounts of inert extenders do not reduce durability appreciably, but larger quantities result in progressive weakening. Sometimes called **filler.**

exterior-DFPA—A grade designation of the Douglas Fir Plywood Association for plywood made with waterproof glue, and intended for permanent exterior exposure.

F

face—The veneer on the exposed surface of the plywood. Where attractive appearance is required, the figure of the veneer is carefully selected and matched. In plywood designed for strength, the emphasis on appearance is subordinated to that of strength. In some locations, like buffet doors, both sides must be of pleasing character, with more careful selection on the exterior side.

fiddle-back—Closely resembles **cross fire** or **cross figure** (q. v.).

figure—Figure is the pattern formed by peculiar or abnormal arrangement of the elements within the tree, as well as by reflected light. This reflection is caused by the unusual alignment of the wood fibres, and by the exposure of the medullary rays. The various kinds of figure are known by many different terms, such as bird's-eye, burl, crotch, blister, etc. (q. v.).

filler—See **extender.**

film—A thin, dry sheet of paper, coated on both sides with a phenol-formaldehyde resin adhesive, of which the best known example is Tego. The film form of adhesive has the advantage of not introducing any water, in the form of glue solvent, that might cause unusual stresses in the face veneer. It also has the merit, in the case of very thin veneers, of avoiding the hazard of steam blisters in hot pressing, which are likely to occur with a liquid adhesive. **Film** sometimes is used to refer to a liquid coating of adhesive.

flake, broken—A breaking or loosening of the flake, or medullary ray, in quarter-cut or sawn veneer, such as white oak.

flat grain—Refers to the grain produced in approximately a tangential direction, or plain-cut veneers.

flexible pressure—See **pressure.**

Flexwood—A trade name, describing cloth-backed, thin veneer, for interior walls, especially plaster and masonry. Applied much as wallpaper is hung.

flitch—The sawn segment from the log from which veneers are cut. The term is also applied to the resulting sheets of veneer, which are kept together, arranged in the sequence of cutting, so that adjacent sheets will have almost identical figure for matching.

G

glue—A term customarily applied to the older conventional cold-setting plywood adhesives, viz.:

albumin, as now used for adhesive purposes, is more correctly called **soluble dried blood.** It is mixed cold and usually

coagulated (set) under heat, but sometimes by chemical reagents. It is highly water-resistant, but little used. Blood is also used as an extender with other adhesives.

animal glue is a derivative of bone and hide waste, usually prepared by cooking. Its application is best accomplished in a warm room and on warmed wood parts. It softens under moisture exposure, and eventually becomes resoluble.

casein is a dried milk product, mixed cold with caustic, lime and other ingredients. Its action on edge tools is abrasive, and it is partly resoluble on exposure to moisture.

liquid glue is a prepared liquid adhesive or **cement,** usually sold at retail. Many types have fish by-products as their base. Not important in the plywood industry.

resin adhesives, see **resin.**

soya-bean meal is the residue of soya bean after the oil has been removed. It is mixed cold with caustic and other substances. It is the only glue that can be applied on wet veneers, but is likely to stain delicately colored face veneers. It is a vegetable protein and, like casein, is only partly resoluble in water.

vegetable glue is a starch product, usually with a cassava root flour base. It is prepared by cooking with caustic and cooled before use. It is widely used in the furniture and plywood industries as it gives an excellent bond dry, but delaminates quickly under moisture exposure.

glue joint—That part of an aggregated wood product which comprises the adhesive (or glue) and the wood parts in contact therewith. Glue joint **strength** is measurable, and is sometimes called **bonding strength.** See **bond.**

grain—A rather general term applied to the vertical elements of wood as it occurs in the living tree. Grain is, perhaps, most easily distinguished in certain woods by the presence of annual layers of more densely aggregated cells or by groups of prominent vessels which form the well-known growth rings. When these are severed they may become quite conspicuous, and the effect produced is referred to as grain.

grain character—The pattern produced by cutting through growth rings and exposing the layers of prominent vessels, thus resulting in a varying pattern. This pattern is most pronounced in lumber or veneer cut tangentially (**flat cut** or **sawn**) or in rotary-cut veneers.

grain, ruptured—A condition of slight breaks in the veneer caused by irregular grain or improper cutting.

growth ring—The layer of wood, made up of springwood and summerwood, added during the year's growth to the outer portion of the tree, just under the bark.

H

hairline—A thin perceptible line, usually showing at a surface joint.

half-round—A manner of cutting veneer to bring out a certain beauty of figure. It is accomplished in the same manner as rotary cutting, except that the flitch is secured on a stay log, a device that permits the cutting of the wood on a wider sweep than when mounted on the lathe center.

hardener for resin adhesives—See **catalyst.**

hardwoods—A general term used to designate lumber or veneer produced from broad-leafed or deciduous trees in contrast with the so-called **softwoods,** produced from evergreen or coniferous trees.

head block, or **retainer board**—A thick (3 to 5 inches) large piece of laminated lumber, usually with veneer crossings, used for bottom and top of a bale of plywood, during pressing and clamping.

heart, or **heartwood**—The darker colored wood substance, usually occurring in the center of the tree. It is also more dense, more decay-resistant, and less resilient than the sapwood, q. v.

herringbone figure—A type of **book matching** (q. v.), used especially with quartered oak veneers, of angling grain, where alternate joints show a "V" effect, while inverted "V" effects appear in the intervening joints.

high-density plywood—Plywood of special construction, made at high specific pressure, usually 500 pounds and up. With the increase in pressure comes a corresponding increase in density, or specific gravity.

humidity (relative)—This term is used correctly to express the relative amount of moisture in air, compared with dry air. It should not be confused with **moisture content** (q. v.) of wood. It is determined by wet- and dry-bulb thermometer readings.

J

Jicwood—See **compregnated wood.**

joint—The line between the edges or ends of two adjacent sheets of veneer or strips of lumber core, in the same plane. An edge joint is parallel to the grain of the wood, while a **butt joint** is at right angles thereto. **Joint glue** may be any type of glue or adhesive used to adhere these edges or ends together. The term is also applied to the surface on which layers of veneer and lumber are bonded together with adhesive. Cf. **glue joint** and **starved joint.** An **open joint** is where there is a visible opening at the point of joining.

K

kiln—Heating apparatus intended for drying. Sometimes applied to a **drier** or **redrier**, q. v., used to remove moisture from veneer, lumber or plywood.

knots—The cross-section of a branch or limb, whose grain usually runs at an acute angle to that of the piece in which it occurs.

knots, open—Where a portion of the wood substance of the knot has dropped out, or where cross checks have occurred to present an opening.

knots, pin—A knot less than ¼ inch in diameter, usually sound.

L

laminated wood—Describes an assembly of wood layers, in which the wood grain or the fibres of the adjacent layers are parallel. Contrasted with **plywood** (q.v.), which is characterized by cross layers or crossings, usually alternated with the parallel face, core and back layers.

lathe—The machine on which rotary and half-round veneer is cut.

layer—See **sheet** or **ply**.

lay-up—The operation of assembling the various layers of veneer or lumber cores, after the glue or adhesive has been applied or inserted, and before pressing.

liquid glue—See **glue**.

log pond—The reservoir of water, where the reserve supply of logs and blocks is stored, usually adjacent to the veneer mill.

longwood—A term, applied rather loosely, to flitches of veneer that are of substantial length. Contrasted with stumps, butts, burls, crotches, swirls, etc., that are relatively short.

loose side—See definition under **tight side**.

lumber-core construction—As contrasted with all-veneer construction (q.v.). The central layer is of lumber, usually edge-glued together from narrow (2 to 3 inch) strips. Lumber cores are seldom less than ⅜ inch thick, and give a lengthwise stiffness to the plywood, as well as a freedom from warp, that does not result from all-veneer construction.

M

matching—A method of placing adjacent sheets of veneer together to afford attractive appearance, viz.:

book matching is accomplished by turning over adjacent sheets of veneer, i.e., like unfolding the pages of a book. Cf. **herringbone figure**.

diamond matching is a process, where sheets of veneer are cut

at such an angle that when four pieces are laid together, a diamond effect is produced. The best results are obtained when the veneer stripes are parallel and equidistant.

four-piece butt matching is a method of trimming to square corners the point where the richest figure occurs in stump or butt veneers. Each four adjacent sheets are then combined with the richest figure in the center.

reversed matching is where alternate sheets of veneer are turned end for end.

slide (or slip) matching consists of laying adjacent sheets of veneer right side up, without turning or reversing, i.e., slipping one sheet beyond the other.

mismatching—Refers to parts of the plywood panel in which the grain character, or the figure of the adjacent portions of the veneer, does not come together symmetrically.

mixer, for adhesives and glue—An open drum-like vessel with a tapering bottom, provided with revolving blades to stir the mixture. There are two types: single or double blades on a vertical shaft; and semi-circular bars on a horizontal shaft, turning inside of each other.

moisture content—This term is used correctly to express the amount (by weight) of water in wood (veneer or plywood), and is computed as a percentage on the oven-dry weight of the wood. The use of the term in connection with atmospheric **humidity** (q. v.) leads to serious confusion.

molded plywood—See **pressure.**

monocoque—A stressed shell construction in aircraft. Usually made of molded plywood (q. v.), without frame members. If a minimum of framework is used it is sometimes called **semi-monocoque.**

mottle figure—Variations in the fibre growth and arrangement that produce a mottled appearance.

O

open joint—See **joint.**

P

panel—Referring to a sheet or piece of plywood.

patches—Insertions of sound wood, placed and glued into veneer or plywood panels, from which defective portions have been removed.

peeler—The trade name of a log, selected and suitable for cutting into rotary veneer. Applies particularly to softwoods, especially Douglas fir.

phenolic resin—See **resin.**

pitch pocket—A defect in the tree, caused by an opening between the annual rings, which may contain an accumulation of pitch.

platens—The heat-bearing plates of the hot press (q. v.). Usually of rolled steel, with drilled holes in intersecting gridiron patterns, for steam distribution.

ply—A **sheet** or **layer** of veneer.

PlyForm—A grade designation of the Douglas Fir Plywood Association, for concrete form plywood, made with highly water-resistant glue. Surfaces are mill-oiled and edge-sealed.

Plymetal—A term used to describe plywood, which has metal sheets for one or more of the layers.

PlyPanel—A grade designation used by the Douglas Fir Plywood Association, for sanded plywood, and further divided into **good 2 sides, good 1 side,** or **sound 2 sides.** It is intended to be exposed and finished on one or both sides, but is not adapted to weather exposure.

PlyScord—A grade designation of the Douglas Fir Plywood Association for unsanded utility plywood that may contain certain defects that do not seriously affect strength and serviceability. One face is made tight by patching. Intended to be covered, and not for exposed finish or painting.

PlyWall—A grade designation used by the Douglas Fir Plywood Association for their wall-board grade. It has 1 side sound and the opposite side is permitted to have certain defects that do not affect strength or serviceability. It is slightly below **PlyPanel** in quality.

plywood—An assembled product, made of layers of veneer and/or lumber and adhesive, the chief characteristic of which is the alternate cross layers, distributing the longitudinal wood strength. This product cannot be split, and shrinking and swelling, under the influence of moisture, is reduced to a minimum. Cf. **laminated wood,** which has no cross layers.

Plywood processes may be employed to assemble the layers of laminated wood, and both are usually made in a plywood factory.

There are also groups of intermediate constructions, predominately laminated, but with a limited number of crossings to impart plywood characteristics.

polymerization—The change that takes place when heat-hardenable (thermosetting) resins are subjected to heat, rendering them hard, strong and insoluble in water. Frequently called the **curing** of a resin. Cf. **setting** in conventional gluing procedure, which, however, is ordinarily accompanied by a loss of moisture, while polymerization can occur in the presence of

moisture. Polymerization is the usual term applied to resin adhesives; **condensation** is a more correct term, chemically speaking.

Pregwood—See **compregnated wood.**

press, cold process—A hydraulic or screw press, in which the glued members are forced together. The pressure is maintained, after removal from the press, by clamping the bale or bundle of glued members between head-blocks, with clamp irons and turnbuckle rods, q. v.

press, hot process—A multi-platen hydraulic press, with plates or platens, heated by steam, for thermosetting resin adhesives. When using thermoplastic resins, cold water connections are provided, for circulating cooling water in the steam areas.

press, hydraulic—Similar to screw presses, but pump pressure is furnished to the hydraulic-press pistons or rams, which usually operate upward in closing. Accurate pressure regulation is practical.

press, screw—A simple form of press, in which the manual or mechanical turning of a screw or of a nut exerts the specific pressure required to bond layers of veneer and lumber into plywood or laminated wood. Used only for cold pressing. Regulation of pressure is difficult.

pressure—The pressure of the liquid medium in the pump and press pistons is indicated by the **pump pressure** gauge. This differs from the **specific pressure** exerted on the plywood. The relation of pump pressure and specific pressure, both in pounds per square inch, is as follows:

$$\text{Specific pressure} = \text{pump pressure} \times \frac{\text{total press piston area}}{\text{plywood area}}$$

Another type of pressure, called **flexible pressure,** is exerted by inflating or deflating a flexible bag, like rubber. It is of the order of fluid pressure, i.e., applied at right angles to any convex or concave surface. Plywood made by this process is called **molded plywood.**

All areas are measured in square inches.

Q

quartered—A method of producing veneer by slicing or sawing, to bring out a certain figure developed by the medullary or pith rays, which is especially conspicuous in oak. The log may be flitched in several different ways to allow the cutting of the veneer in a radial direction.

quilted figure—A more euphonious term for **blister figure,** q. v.

R

railing—See **banding.**

redrier—Plywood pressed cold with liquid glue has a substantial surplus of glue solvent (water), which must be removed before the plywood will become normal and stay flat. Active air circulation at 100° to 120°F., and 50 to 60% relative humidity, is required.

Redriers for veneer are somewhat like a hot press, with steam-heated plates, but only enough pressure to keep veneers flat. The plates are raised and lowered alternately (**breathing** it is called) to allow moisture to escape and prevent veneer from checking.

resin—A raw material, made synthetically, which is the basis for products called the plastics. Certain resins can be used to adhere pieces of wood, and these are called resin adhesives, less correctly resin glues. These adhesives are of relatively recent development and are much more durable than the older types of conventional glues.

Phenolic resin adhesives are made from **phenol** and **formaldehyde**, harden only in the presence of heat, and are the most durable. They are available in liquid, powder and film form.

Urea resin adhesives are made from **ureas** and **formaldehyde,** harden when heated, and in the presence of certain chemicals (catalysts or hardeners) this hardening can be rapid and at moderate temperatures.

retainer board—See **head block.**

reversed matching—See **matching.**

ribbon stripe—A type of veneer figure, consisting of alternate light and dark strips, running more or less the length of the sheet, and varying from less than ¼ inch to more than 1½ inches in width. It is pronounced only in quartered or nearly quartered cutting. It is usually due to differences in the reflection of light from adjacent layers of wood, cut from trees with interlocked grain.

rope figure—A succession of short cross fire, remotely suggesting the twist of a rope.

rotary cut—A manner of cutting veneer, by which the entire log or block is mounted in a **lathe,** and turned against a broad cutting knife, which is inclined into the log at a slight angle. The veneer is cut in a continuous sheet, from the circumference of the block, somewhat as paper is unwound from a roll.

S

sampling—A method of selecting and marking representative samples of sliced or half-round veneer, from the top, center and

bottom of a flitch. Samples are usually hinged with cloth tape to fold into a sample trunk for sales display. Used also for stockroom records.

sap, or sapwood—The lighter colored wood substance, usually occurring in the outer portion of the tree, nearest the bark, and more susceptible to decay than the heartwood.

sap stain—Discoloration caused by miscroscopic fungus growth in the cells of the sapwood.

sawn—Some veneers, as quarter-sawn oak, are made on segment saws. It is claimed to produce more solid veneer, although much more costly, because of saw-kerf waste.

scarf—An angling joint, made either in veneer or plywood, where pieces are spliced or lapped together. The length of the scarf is usually 12 to 20 times the thickness. When properly made, scarf joints are as strong as the adjacent unspliced material.

setting—The hardening of a cold-pressed glue. It is brought about, largely, by the evaporation of the glue solvent, either with or without heat. Cf. **bond** in resin adhesives.

shake—Physical separations of the annual **growth rings** (q. v.).

sheathing—Plywood used in the construction trades for the under covering of walls, roofs or floors. Commonly grade marked "PlyScord" by the Douglas Fir Plywood Association.

sheet—A single ply, or layer of veneer.

shim—A long narrow patch, glued into the panel, or into the lumber core.

sliced—A manner of cutting veneer, by which logs or sawn flitches are held securely against a table in a slicing machine. The table is moved down, and at an angle, across a sturdy knife, which shears off the veneer in sheets.

slide or slip matching—See **matching.**

softwoods—A general term used to designate lumber or veneer produced from coniferous, or needle-leafed, trees, as contrasted with hardwoods from broad-leafed trees.

solid piled—Sometimes called dead piled or bulked down. Plywood, fresh from clamps or hot press, is piled on a solid, flat base, without stickers, and weighted down to become normal as to heat and moisture content.

soya-bean meal—See **glue.**

specific pressure—See **pressure.**

splits—Separations of wood fibre running parallel to the grain.

spread—The amount of glue or adhesive, in pounds of liquid mixture, that is applied per thousand square feet of single adhesive line. In conventional cold glues, usually 70 to 90

pounds, in resin adhesives from 25 to 35 pounds. On the Pacific Coast the term "spread" often applies to weight of **dry glue**, per thousand square feet of double line, i.e., 3-ply. This term requires adequate explanation to avoid misunderstandings.

spreader—A double corrugated roller machine to apply coatings of adhesive on both sides of the veneer, preparatory to the lay-up. Metal rollers are used principally with **glues**, and rubber rollers with **resins** adhesives (q. v.).

springwood—The portion of the annual growth ring that is formed during the early part of the season's growth. It is usually less dense and weaker mechanically than summerwood.

stain—Any discoloration of the wood substance. Common veneer stains are often produced by the chemical action of the iron of the cutting knife with the tannic acid in the wood, as well as by the chemical action of the glue.

starved joint—An expression used to indicate an inadequate amount of glue or adhesive, either because of insufficient spread, too rapid absorption into the wood substance, or in some cases, with dense woods, of too much pressure.

stay log—An attachment for a veneer lathe, on which flitches may be mounted for cutting into half-round veneer.

stickers—Wood pieces, approximately ¾ inch square, to be laid between sheets of freshly completed plywood, to permit either the drying or cooling of the plywood surfaces. They should be uniform in size, and laid in a vertical line, across the plywood, in the direction in which it is most likely to warp.

streaks, mineral—Natural discolorations of the wood substance.

stripe, broken—See **broken stripe.**

stripe, ribbon—See **ribbon stripe.**

stump veneer—Veneers cut from the sound roots of a tree, such as walnut, and having a rich, curly figure, resulting from the intertwining of the root fibres.

summerwood—The portion of the annual growth ring that is formed during the latter part of the yearly growth period. It is usually more dense and stronger mechanically than the springwood.

sunken joint—A term describing small, straight depressions in the plywood surface, directly above the joints in the lumber core, or in the crossbanding. Caused by inadequate drying of the glue solvent before planing lumber cores, or by uneven thickness of the crossband veneer.

super-pressed plywood—More correctly called **high-density plywood** (q. v.).

swatch—Method of sampling veneers, consisting of selecting a single sheet of veneer, 3 feet long and the full width of the flitch, taken usually near the center, to represent truly the color, texture and characteristics of the flitch. Used especially with moderately plain walnut veneer.

swirls—Irregular grain, usually surrounding knots or crotches.

T

tape—The strip of gummed paper or cloth used to hold the edges of the veneer together, at the joint, previous to gluing.

Tego—The original and best known phenol-formaldehyde resin film.

testing—Methods of determining strength and durability of plywood and adhesives.

texture—Surface characteristics.

thermoplastic—A term used to describe a material which tends to soften when heated. A thermoplastic resin, used as an adhesive, normally requires hot pressing, but the pressure cannot be released until the temperature has been reduced (cooled) to a point at which the resin hardens.

thermosetting—A term used to describe a resin, adhesive or otherwise, which hardens when heated, and does not again soften when reheated. No cooling is required before the release of pressure when plywood is made.

tight side—This term, and its opposite, **loose side**, are used to refer to veneer cut with a knife. A wedge-shaped or beveled knife is used, and the veneer comes out curved away from the knife, thus producing small ruptures on the concave side, known as the loose side. The opposite surface, slightly in compression, but free from any ruptures, is known as the tight side.

turnbuckle rods—See **clamp irons.**

two-ply—A reinforced, veneer face construction in which fragile veneer, such as stump or burl, is reinforced by a 1/40- to 1/60-inch cross-laid backing veneer of birch or maple. It is usually bonded with a resin film, and is primarily intended to prevent damage to fragile and costly veneer in handling.

U

Uformite—A widely used urea resin adhesive. See **resin.**

urea resin—See **resin.**

V

vat—See **cooking vat.**

vegetable glue—See **glue.**

veneer—A thin sheet or layer of wood, sliced, rotary-cut, half-round or sawn from a log, block or flitch. There is no saw-kerf waste in knife-cut veneer (excluding sawn), as contrasted with lumber, hence there is a more liberal yield of raw material. Veneer is the raw material from which plywood and laminated wood are assembled. Thicknesses may vary from 1/100- to ¼-inch, and are seldom thicker.

veneered wood, or **veneering**—An outmoded term to designate **plywood.** The unpleasant connotations with superficiality in dictionary definitions prompted the industry to abandon these terms many years ago.

vertical grain—Same as **quartered grain** (q. v.).

W

wall board—Plywood used in the construction trades for wall covering that may have interior exposure.

wane, or wany—The tapering or angling edge of a board or sheet of veneer, due to the round shape of the log, that was not properly trimmed off.

warp—A variation from the true or plane surface. Usually caused by uneven moisture content in the two sides of a layer of lumber, veneer or plywood.

Weldwood—Trade designation of the United States Plywood Corporation, applied to all of their plywood. When branded **Waterproof Weldwood,** the product is resin-bonded and suitable for exterior uses. Further designations, **aircraft** or **marine,** indicate purposes for which such plywood may be used.

working life of resin adhesives—The period during which a mixture of a resin adhesive remains alive (suitable for spreading) before hardening in the receptacle, or commencing to gel appreciably.

SECTION ONE

BRIEF HISTORY OF PLYWOOD

THE ORIGIN OF PLYWOOD

Plywood consists of fabricated veneer and glue, just as shoes are made of leather and thread, hand tools of steel and wood, books of paper and ink, and the like. In order to trace its early history it is necessary to uncover the story of its elements, and how they came to be put together.

What is Plywood?

Plywood, as the word is understood today, is a relatively recent product, its general use dating from shortly after the Civil War. In its simplest form it consists of three layers of thin wood, firmly glued together, with the grain direction of the middle layer at **right angles** to that of the two parallel outer layers. A conspicuous characteristic of wood is that it has a grain and that it absorbs moisture by exposure. When moisture enters the wood, the piece swells, but only across the grain. When the moisture dries out the wood shrinks, i.e., becomes narrower. By placing the middle layer of thin wood with its grain running across those on either side, then binding them together with a glue, this swelling and shrinking is reduced. It is important to keep the layers of plywood in approximate balance, i.e., neutralize as far as possible this tendency to "come and go" under moisture changes, and hence the central layer should be as thick as the total thickness of both outer layers. Obviously this crossing of the grain and gluing together imparts to the new product a stability and strength not found in the original material. From this simple form and rudimentary principle has grown a tremendous industry, with products that serve a wide range of human needs, ministering to man's comfort and appealing to his sense of beauty.

Veneer in Plywood

Veneer, one of the constituent elements of modern plywood, is a far older product, and, in the expressions **veneered** and ve-

neering, has been used to describe many products in the plywood family, consisting of one or more surface layers of thin wood, usually of a decorative character. Until within the last hundred years such veneer was produced by hand or by the use of very primitive tools. As a result its use was rather narrowly limited to the more costly species of wood, and its products could only be enjoyed by those whose wealth permitted them to buy comforts and luxuries that were denied to all but the more important personages in the successive eras of human history.

It is not surprising that such a product as veneer, used largely for decorative purposes, should eventually come to designate a layer or surface that covered up what was less beautiful, whether or not such covered up material was a sturdy base for the attractive surface, or was merely an unsightly part that might be inferior or did not please the eye. It would not have been strange for unscrupulous workmen of past years to endeavor to cover up their mistakes or weaknesses, even as is done today. As the years and centuries rolled along the term veneer came to have a double meaning. To those who spoke intelligently it indicated a beautiful display of wood, one of nature's gifts to mankind everywhere, properly attached to a sturdy base and honestly put together. Others, and they were in the majority, believed or assumed that it was merely an attractive surface that was likely to conceal poor workmanship and inferior material.

Most dictionaries and encyclopedias, as they came into existence, followed the opinions and ideas of the majority, or what is often termed common usage. The true, and more exact, meaning almost disappeared. Thus we find practically all definitions, up to a few years ago, describing veneer in quite uncomplimentary and unfavorable terms. The following are a few examples:

"a veneer of civilization"

"a veneer of respectability"

"a rogue * * veneered with sanctimonious theory." Tennyson.

"veneered so as to give the whole the appearance of being of the more valuable material." Century Dictionary.

The process and method leading to the adoption of the more modern term, plywood, will be outlined more fully on pages 35-6.

A brief outline of the origin and growth of the art of veneering is necessary to understand the background from which modern plywood has grown to its present maturity.

Early Decorative Uses of Veneer

Ancient Egypt

The earliest known evidence of the existence of the art of veneering was discovered in the Sculptures of Thebes, dated as early as the time of Thothmes III (c. 1500 B.C.). His wealth and accomplishments rank him as the greatest of all the Pharaohs. Sir Gardner Wilkinson, a distinguished British archaeologist, presents a line reproduction (Fig. I. 1) of a famous mural record that has been credited to the reign of Thothmes III. While the keyed description, as printed, is largely that of Wilkinson, the author has, after many years of study and consultation, made some revisions that seem more logical from a woodworker's standpoint than the original explanation in the Wilkinson publication.

Reproduced from "Manners and Customs of the Ancient Egyptians," Wilkinson.

Fig. I. 1—Veneering in ancient Egypt. Mural record of veneering discovered in the Sculpture of Thebes, dated in the reign of Thothmes III, c. 1500 B.C.

1—workman exhibiting an example of veneering: (*a*) piece of dark-colored wood applied to a lighter piece *b*; (*c*) adze fixed in block *d* of color *b*, and from which *b* has apparently been cut; (*e*) ruler or straight edge, and (*f*) right angle or square; (*g*) view of a finished, veneered cabinet or stand.

2—workman pressing sandbags, *l* and *m*, probably heated, on plywood assembly *n* while the glue dries and sets: (*i*) pot of glue, over fire *h*; (*j*) lump or cake of flake glue, and *k* probably dish of crumbled glue.

3—workman spreading glue on sheet of veneer. (Some authorities suggest that *p* is a knife with which the veneer is being cut to desired shape.) (*p*) brush for spreading glue (or knife for cutting veneer); (*o*) stand or table on which veneer is laid to spread glue (or to cut veneer).

It is quite evident that the rudiments of woodworking and the practical use of glue were well understood at that far-distant date. The thin sheets of veneer were hand hewn from contrasting colored woods, were spread with glue and superimposed upon each other, and weighted down with sandbags, in lieu of clamps or presses. The glue was broken up from flakes or lumps, and softened by heating over the fire. It was undoubtedly a primitive kind of what is now known as animal glue.

Only a few pieces of early Egyptian furniture are now extant, mostly rescued during the last century from sealed tombs. These

few give ample and irrefutable evidence of overlaying and inlaying with veneer, ivory, metals and precious stones.

Classical Greece

Furniture, such as we have today, was not much used in Greek homes, as the Greeks were an outdoor and athletic race, with simple houses. Ransom states that "Wooden couches were . . . sometimes beautified by veneers of finer woods, such as box." Greek architecture, however, gives evidence of the skillful use of beautiful woods. The Greeks are credited with originating the table, a modification of the sacrificial altar, and the couch or bed, including the day bed as well as the folding bed for traveling and moving about.

Roman Empire

Pliny states, some two thousand years ago, that the proudest possession of Caesar was a table beautifully veneered. Litchfield writes of the time of Augustus (63 B.C. to A.D. 14):

"Veneers were cut and applied, not as some have supposed for the purpose of economy, but because by this means the most beautifully marked or figured specimens of the woods could be chosen, and a much richer and more decorative effect produced than would be possible when only solid timber was used."

Pliny's *Natural History,* Book XVI, devotes the whole of Chapter 84 to veneering. Unfortunately he does not tell us how the woods were cut into veneers, stating only:

"The best woods for cutting into layers, and employing as a veneer for covering others, are the citrus, the terebinth, the different varieties of maple, . . . the root of the elder and the poplar."

Even in that far-distant era the use of stump or butt veneer was known, and it is one of the most attractive types of veneer that we know today. At another point in this chapter Pliny continues:

"In order to make a single tree sell many times over, laminae of veneer have been devised."

This is a striking suggestion of the conservation of timber.

France in the 17th and 18th Centuries

After a long gap, during the Middle Ages and the Renaissance, we find a marked revival of the artisanship of woodwork and veneering, culminating in the "Bureau du Roi," begun for Louis XV in 1760 and finished and signed by Riesener in 1769. It is the plywood masterpiece of all time and one view of this remarkable piece of workmanship is shown in Fig. I. 2. It is a prototype of the modern roll-top desk and is said to have cost the king more than a million francs.

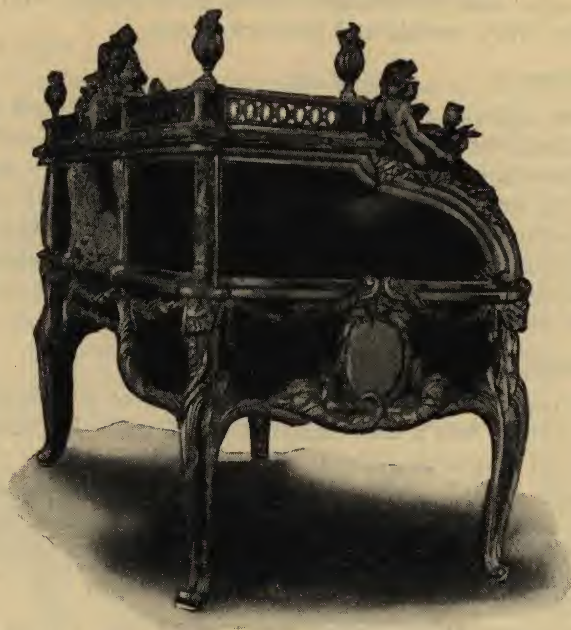


Fig. I. 2—Bureau du Roi, Louis XV, 1769.

Napoleon's "Bureau de Campagne" is said to have been carried on many of his military campaigns. It is an early form of knee-hole desk, veneered throughout with rosewood, and still preserved in excellent condition.

Period Furniture

The classic furniture of these periods, from about 1700 to 1820, mostly in England and Europe with some in the American Colonies, emphasizes the use of walnut and mahogany veneers. These types still supply the background for the graceful designs of a large part of the better furniture that is made today. A complete description of these periods, with salient design characteristics, can be found in the Johnson-Sironen Manual, noted in the Bibliography.

Early Machinery for Veneer Production

Saws

The earliest mechanically operated saw was of the reciprocating blade type, if a man can be correctly called a source of mechanical power, and is shown in Fig. I. 3. This was built in single or gang

units and is known to have been in use about 1650, quite possibly earlier. One of its uses was undoubtedly cutting thin boards for veneer.

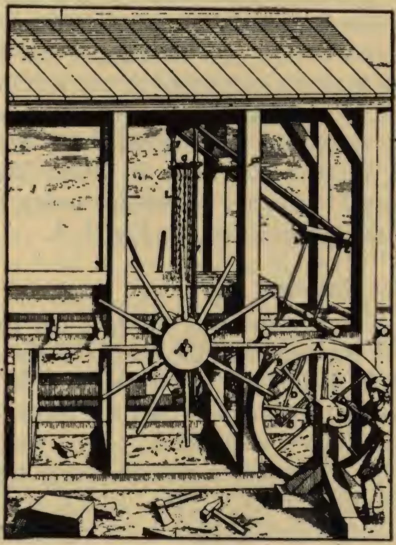


Fig. I. 3—An early saw mill, c. 1650.

The first patent on a circular saw appears to have been granted in England to Samuel Miller, August 5, 1777, but it did not reach the

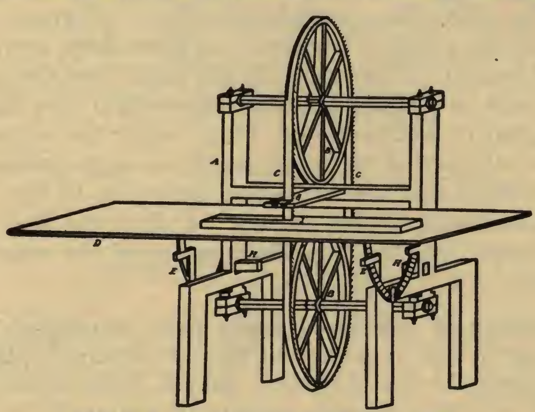


Fig. I. 4—Newberry's band saw, 1808.

Drawing and description copied from English Patent 3105.
A—cast iron frame to carry wheel shafts. *BB*—wheels with iron plate screwed behind to prevent saw from running off backward. *CC*—blade of saw. *D*—operating table. *EE*—cast iron arcs for regulating the tilting top, for angle sawing. *G*—saw guide. *HH*—wedges on lower wheel shaft to give tension to the saw blade. *I*—board in process of cutting.

point of much utility until about 1805, shortly after the advent of the steam engine. Its use was stimulated by the development of steam power, but it did not come into general use until about 1840, when the art of inserted teeth greatly widened its application to industry. Circular saws were very wasteful in saw kerf, which at that time was far more than the thickness of the resulting veneer.

Band saws, continuous or endless, could be made of much thinner steel than circular saws, and their invention is first recorded in the English patent of William Newberry in 1808. Their use was quite limited, in the general form they are known today, until around 1870. The Newberry band saw is shown in Fig. I. 4.

Veneer Planers or Shavers

A large power-drawn plane was brought out in the early 1800's and was a type of shaving machine to cut slices of veneer. Again the steam engine facilitated its operation, but there is no evidence that it was extensively used, and in fact the record seems to indicate that it was not particularly successful.

The most epochal invention in woodworking machinery was that of Sir Samuel Bentham in 1793 (No. 1951). He was an Englishman, educated at Westminster, who in twenty years rose to be brigadier-general and inspector-general of the naval works of England. His brother, Jeremy Bentham, the famous writer on political economy, was in charge of several industrial prisons, where the inmates seemed incapable of learning a manual trade, of which woodworking was then the chief. Sir Samuel, therefore, undertook to develop machines for the principal woodworking operations previously done by artisans trained in the trade, feeling that even the unambitious prisoners could be taught to run a machine and thus carry on the prison program of woodworking. Thus, under the stress of prison economy, was launched the most ambitious aggregation of woodworking machines that the world had known up to that time. The patent included the following sections, of which the first and fourth give clear insight into the later development of the veneer and plywood industry:

1. **Formations of laminated wood from shavings**—The shavings referred to are veneers, cut by the Bentham planer. This claim describes the first plywood panels, with additional specifications for winding veneers spirally on mandrels to make hollow tubes.

2. **Sawing by reciprocate motion**—the first jig-saw.

3. **Working by reciprocate lathe**—the ancester of the metal-working planer.

4. **Giving curvature by bending**—Bentham claims originality for his specified process of building up a thick section in thin plies, making it easier to bend.

5. **Working by rotative motion of tool**—Describing circular saw-tables, molders and shapers, with their auxiliary devices.

6. **Boring**—single bits, double-end boring, and multiple-spindle drills.

7. **Mortising**—flat-end bits for blind mortises, with square ends.

8. **Turning on a lathe.**

9. **Adjustment and steadiment.**

10. **Advancement**—Comprising methods for mechanically moving stock into the field of the cutting tools.

11. **Clearance**—for chips and sawdust.

It can well be questioned, whether before or since, any one man has rendered such a comprehensive service to the woodworking industry.

Lathes for Veneer Cutting

The first distinct veneer-cutting device was a modified turning lathe, on which an American patent was taken out by John Dresser

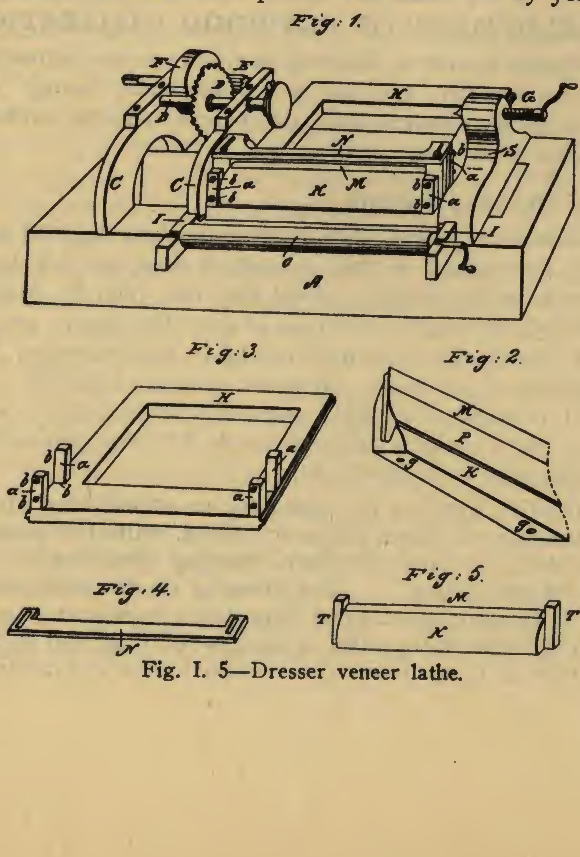


Fig. I. 5—Dresser veneer lathe.

of Stockbridge, Massachusetts, No. 1758, September 3, 1840. This is shown in Fig. I. 5 and is described as consisting of a strong wood or iron frame, upon which rest two iron stands, supporting an arbor or mandrel, turning against a knife, and cutting veneer in a continuous sheet. It is further specified that "water, steam or horse power may be used to propel the machine . . . or by . . . a crank upon . . . the cog wheel it may be propelled by hand."

The single claim is quoted in its entirety and is very comprehensive:

"The particular manner of cutting veneers with a knife from cylindrical blocks of timber revolving in a common turning lathe or other similar machine, as herein set forth."

Veneer Slicers

This apparently was the last of the veneer-production machines to be developed and is known to have been in use before 1875. Its cutting mechanism was very similar to that of the veneer lathe, but was actuated by a pawl and racket device to feed the knife into the flitch, and at the same time to regulate the thickness of the sheets of veneer.

DEVELOPMENT OF PLYWOOD UTILIZATION

It is a difficult matter to discover just when a new industry establishes its own identity, and can be considered as having "come of age," so as to be distinct from the parent industry under whose shadow it has grown up.

Records of Plywood Patents

In such cases the patent office is often the best diary of industrial events, and fortunately, in this instance, it does not fail us. Patent Office records in Washington reveal that one John K. Mayo, "formerly of Portland, Maine, and now of the city, county and state of New York," took out a patent, No. 51,735, on December 26, 1865, and at least three re-issues, all dated August 18, 1868.

The first re-issue, No. 3,085, uses the term "scale" or "scale-boards" to refer to a thin sheet of wood. The description that follows is unusually farsighted, viz.:

"The invention consists in cementing or otherwise fastening together a number of these scales or sheets, with the grain of the successive pieces, or some of them, running crosswise or diversely from that of the others. . . The crossing or diversification of the direction of the grain is of great importance to impart strength and tenacity to the material, protect it against splitting, and at the same time preserve it from liability to expansion or contraction."

This first re-issue describes a "new and useful material for the formation, covering or lining of various structures," a glimpse of future plywood houses.

The second re-issue, No. 3,086, is equally comprehensive and states:

"The invention consists in the formation of various structures used in Civil Engineering of a plurality of thin sheets or veneers of wood, cemented or otherwise firmly connected together, with the grain of the several scales or thicknesses crossed or diversified, so that they will afford to each other mutual strength, support, and protection against checking and splitting, shrinking or swelling, expanding or contracting."

The drawings show a tubular bridge, like an enormous pipe, a similar rectangular tubular bridge, and a section of pavement. The list of applications includes all manner of projects, bridges, railroad tracks, docks, forts, canal locks, aqueducts, sewers, pneumatic tubes for postal service, all enumerated at great length.

The fifth re-issue, No. 3,089, applies the art to what would now be called house furnishings, illustrating a chess table with inlaid top, a rocking chair, and a window shade, wound on two rollers and described as follows:

"The window-shade may be made of two or more layers or laminae of wood as thin as paper, the grain in one layer running in a diverse direction from the other layer."

The exhaustive list of furniture items and household equipment enumerated, all of veneered construction, would tax the facilities of a modern department store. A further paragraph is really a prophetic vision of the method of making plywood trays of the "Toastmaster" type, that did not materialize until some seventy years later, viz.:

"By adopting the well known process of wet and dry heating in course of manufacture, the several scales of wood may be brought to such a state of pliability as to assume any desired form by compression in a matrix or upon formers and by using different degrees of thickness, in connection with cements of different kinds, the character of the article made may be either rigid or flexible."

It is doubtful whether Mayo benefited greatly by his remarkable grasp of plywood possibilities, as has been true of inventors since the beginning of time.

The next important patents are those of George Gardner, of Brooklyn, New York, originally dated May 21, 1872, and re-issued on July 4, 1876. These refer particularly to perforated chair seats, and a layer of canvas is suggested to give added strength.

As would be expected, the term plywood does not appear in any

of this early patent art, in fact it did not really become a trade name until the war period of 1914-18.

Plywood in Pianos

It appears quite certain that the piano industry was the first to use plywood, as we now know it, dating back to about 1830, when thin sawn maple was cross laid into pin planks or wrest planks. The tuning pins are forced into holes in this pin plank, and the pins must be so gripped by the wood fibres, that the pins will never slip, but can be turned to tighten or loosen the wires and thus facilitate the proper tuning of the piano. The fundamental principle of cross laying alternate layers of wood gave the shank of the pin constant contact on all sides against the ends of the wood fibres. It is interesting to note that pin planks have continued to consist of such plywood for over one hundred years, and it is still the standard method in practically all grades of pianos.

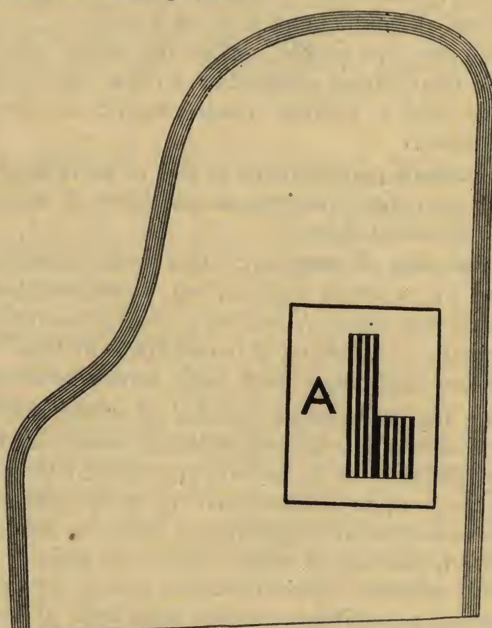


Fig. I. 6—Laminated rim of a grand piano.
Cross-section of outer and inner rim shown at *A*.

Another early use of veneer in piano construction was the grand-piano rim, which dates from about 1860 in the piano factory of Steinway & Sons Company. This was glued up, while bent to the proper curve, over a form, combining 8 to 12 layers of sawn veneer, with

the grain direction of all layers parallel. While not strictly a plywood construction, and ordinarily called laminated wood, it did utilize the opportunity that plywood offers to bend thin layers of wood into desired curves and glue them together while clamped on a rigid form. An outline of such a rim is shown in Fig. I. 6. The outer rim is the full height of the piano body, with an attractive exterior veneer face. The inner rim, similarly made, is only half as high as the outer, is nested and glued inside the outer rim, and furnishes a support for the main cast iron frame, that is virtually the backbone of the piano. This method of grand-piano rim construction is still standard in 1940, and is recognized by all piano makers.

Plywood in Sewing Machines

The Sewing Machine Cabinet Company of Indianapolis was started about 1867, by the Wheeler & Wilson Sewing Machine Company, to make plywood parts for various sewing-machine cabinets. At first they are reported to have used only sliced veneer, but after acquiring a veneer lathe about 1870, they commenced to use rotary-cut crossbands or crossings. So far as known they did not use what are now known as lumber cores in their plywood.

Plywood in Seating

Gardner & Company of New York City, another pioneer plywood organization, made curved and perforated seating for railroad and

Fig. I. 7—Perforated plywood seating, popular for stations and lodge halls about 1875.

ferry stations as are shown in Fig. I. 7. This and the following illustration are taken from a catalog published in the mid-seventies. This is the first recorded use of cross-ply curved plywood where the layers were bent in the forms while the glue was still wet. After the glue dried and became set, the curve was rigid and strong enough to carry its human load. The perforated designs and mottoes are quite intriguing. In many ancient stations the name of the original railroad company, long lost in the mergers and consolidations of the gay nineties, is preserved in the perforated seating—a possible argument that plywood is more lasting than railroads.

The Gardner of this firm is the patentee mentioned above.

The large sheets of veneer used in these settees resulted in many small sheets of veneer, that, as a by-product, were made up into chair seats and backs as shown in Fig. I. 8. Perforated chair seats are still made and used in many localities, but the holes are now punched out with gang punches, while the earlier holes were laboriously bored out, one by one, by youngsters of those olden days, long before child labor was recognized as a social problem.

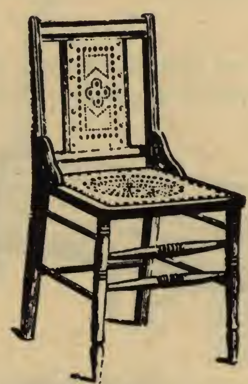


Fig. I. 8—Perforated chair seat and back, about 1875.

Plywood in Organs

The Indianapolis Cabinet Company, successors to the Sewing Machine Cabinet Company above, was organized in 1879, broadening the name to cover a wider range of plywood products. While it continued to make parts for sewing-machine cabinets for Singer, Wheeler & Wilson, Howe and others, it also developed a new line, supplying plywood bellows, cabinet ends and fretwork for the

ubiquitous cabinet organ that was the principal source of homemade music in the closing years of the last century.

Plywood Desk Tops

Solid lumber desk tops, or writing beds, were always troublesome, with many open cracks and much warping. The framed desk top, with mitered corners and a leather or oilcloth center with fancy taped edges, lingers in many memories, but was not the answer to the desk top problem. The plywood desk top with lumber cores is known to have been developed about 1883 in the plant of the Indianapolis Cabinet Company above. It was hailed as a great improvement and by 1890 a number of manufacturers were producing it, and it soon became the recognized standard.

Furniture Plywood

The plywood used in furniture divides into two rather distinct groups: **thin panels,** of all-veneer construction, used mostly for concealed or semi-concealed locations, like drawer bottoms, mirror and case back, dust bottoms and somewhat for end panels that are set in grooved frames; and **tops** and **fronts,** usually of lumber-core construction, where appearance and stability are important. While veneer had long been used for decoration in furniture, as history indicates so clearly, yet the all-around advantages of plywood were little appreciated until around 1890. One of the early pioneers of the Michigan-Wisconsin area used to tell of his unsuccessful attempts to sell plywood tops to the trade. They were derisively called "pasted wood." But in spite of the traditional conservatism of the woodworker, the amount of plywood used in furniture grew by leaps and bounds, and new plywood plants sprung up, east, west and south, from about 1885 to 1900.

As manufacturing technique improved, it became possible to offer a more sturdy and attractive suite of furniture of plywood construction at a lower price than the former suite of solid lumber, which was distinctly inferior in appearance, workmanship and material. Thus the use of plywood has helped to introduce better furniture to a greatly broadened customer market.

Plywood Doors

Plywood gradually became a factor in door construction, first in panels about 1890, where its strength and stability far outdistanced the quality of the raised panels of solid lumber construction which were elaborately scarfed thin at the edges to fit in grooves. The flush

or slab door began to be popular considerably later because of its sturdiness and sanitary features. A flush door could only be made successfully of plywood, since the range of moisture and temperature exposure on the two sides made a flush lumber door wholly impractical. Still later the stiles and rails of panel doors came to be made of plywood, largely because of dimensional stability, which was never a characteristic of any product made of solid lumber. The door-manufacturing business of the last half century has mostly centered in the Mississippi Valley region.

Plywood Sleighs

The body of the horse-drawn sleighs of yesteryears was invariably made of plywood, and the "S"-shaped dashboard was a special plywood construction to allow bending in either direction. While the sleigh is nearly extinct as a species, it lingers in many memories, and was, at its prime, a large outlet for plywood. The outline of such a sleigh (Fig. I. 9) clearly shows the "S"-shaped dashboard. The plywood was held in proper curvature by bent steel bands, and where the grain of the veneer was opened on convex surfaces, it was liberally filled with many coats of paint.

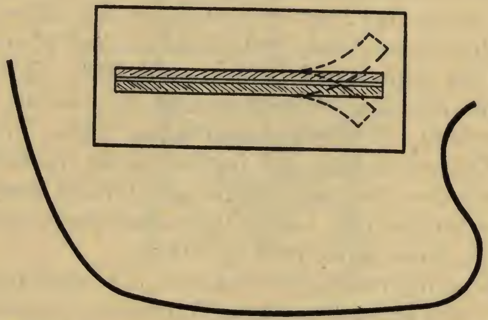


Fig. I. 9—Contour of flexible plywood sleigh.
Inset shows detail of flexible plywood, thick outsides and thin centers, that would bend easily against the grain of the center.

Barrel-top Trunks

This familiar item of present-day attic equipment originated in the 1890's, and was a plywood creation of great interest and value. Its protective feature of preventing the crushing of the trunk contents made it far preferable to any of the preceding flat-topped chests, and it was much lighter in weight. Its success and efficiency were due to its plywood construction.

Stock Panels

The earlier utilization of plywood was based on custom-made constructions and sizes for special purposes. The idea of an all-purpose and general-utility plywood does not appear until about 1905, when the use of the stock panel is first recorded. The original sizes, 3 by 6 feet, have now been increased to 4 by 8 feet. It permitted the user to carry a stock of the various standard constructions that could be cut down quickly to any special requirement, a distinct saving in time and often in cost. The use of stock panels, in both hardwoods and softwoods, has grown to large proportions, and adequate warehouse stocks are now carried in the larger cities. (See pages 86-9.)

Plywood Shooks

One of the earliest uses of veneer, for vegetable and fruit baskets, crates and boxes, antedates commercial plywood by several decades. The plywood shook, an outgrowth of this package use of veneer, is known to have been in use around the turn of the century, perhaps earlier. While crudely made, according to modern plywood standards, it combined strength and lightness, and became a very popular shipping container. While the corrugated paper box has invaded this field, the plywood shook is still a well recognized and widely used package.

Plywood on the Pacific Coast

It seems quite clear that the cutting of veneer on the Pacific Coast originated about 1890, when a veneer lathe was set up in Tacoma, but its product was used principally for baskets and fruit packages. It is to be noted that some of this early Pacific Coast veneer, alder and cottonwood, was shipped to Grand Rapids for use in furniture manufacture. Douglas fir, one of the major species now used in structural plywood, is not known to have been made into plywood until about 1905, when a few Douglas fir plywood panels were exhibited at the Lewis and Clark Centennial Exhibition (Portland, 1905). It is an interesting contrast to learn that in 1939 the major part of many buildings in both the New York and San Francisco fairs was constructed of Douglas fir plywood. These panels of 1905 were handmade at Portland in manually operated presses using animal glue spread with a brush. Mechanical production began about 1910, and the three existing plants, for the next few years, made panels for doors as their principal product. The distinctly structural plywood that has carried the name of Douglas fir plywood all over the world did not begin to appear until about 1920. This branch of the

plywood industry has developed most remarkably, as can be seen from these annual production records:

1925	153,000,000
1930	305,000,000
1935	491,000,000
1936	700,000,000
1937	725,000,000
1938	650,000,000
1939	925,000,000
1940	1,150,000,000

(Square feet area, ⅜ inch thick)

The enterprise and experience of these western plywood producers have resulted in a vast volume of "sheeted" lumber that finds a wide range of structural and industrial uses. The Douglas Fir Plywood Association, established in 1938, is proving to be a most efficient co-ordinator in furthering the use of this type of plywood.

Other Plywood Adaptations

By the beginning of the present century, plywood had become reasonably well established as a new form of wood material with distinct advantages over solid wood, and its use extended rapidly into many industrial and construction fields. In this more recent period it becomes more difficult to distinguish the beginnings of the use of plywood in many new applications. As an industry grows and its leaders recognize its reasonable possibilities, it becomes less easy to classify its ramifications in the broad fields of plywood utilization.

Its increasing use in furniture and the allied industries is perhaps the first evidence of this broadening. Few pieces of furniture are now made wholly without plywood. From the piano and the organ its utility spread into the phonograph and radio cabinet field. From the building of bodies for carriages and sleighs it moved forward as a desirable and useful material for trucks, busses, trolley cars, railroad cars and automobiles.

Its entrance into construction work resulted from the advantages that accrued from the use of large areas instead of relatively narrow boards. This made plywood especially economical in such uses as sheathing, sub-floors, partitions, concrete forms, bins, chutes, etc. This development, however, was largely subsequent to the advent of Douglas fir plywood on the Pacific Coast.

The airplane maker immediately recognized the outstanding strength/weight advantages of plywood, and most early planes were largely wood and plywood. The lack of proper waterproof adhesives soon curtailed its use in the rapidly growing aircraft industry, and the designers swung over almost entirely to the use of the newly

developed light metals. With the appearance of hot-pressed resin adhesives, around 1930, the waterproof characteristics of resins became well established, and now aircraft makers are distinctly returning to the use of plywood. The favorable qualities of plywood make it useful to the airplane designer as a wing and fuselage covering, as a means of sturdy and light spar construction, for reinforcing and gusset plates, for propellers and many other minor uses.

The availability of thoroughly waterproof plywood, of the hot-pressed types, opened wide the opportunities in watercraft. In the 1930's, mostly in the last five years, plywood entered extensively into the building of large numbers of canoes, dinghies, racing craft, speed boats, row boats, yachts, coast-guard cruisers and the like. Plywood finds its utility in plywood hulls, bulkheads, decking, cabins and has even been considered for hollow spars and masts.

Still other recent developments are the plywood tennis racket, now widely displacing solid, bent-ash frames. The plywood roller-skate wheel is another novel adaption. Plywood trays and serving equipment of many preformed types are much in vogue. Game boards and tables are an important plywood outlet.

The opportunities for plywood utilization appear to be constantly widening and the new fields seem more promising than ever before.

This more or less chronological list is merely an outline of when and how plywood came to be used in such widely diversified products. A more complete description of such applications and adaptations will be found in Section IV.

PLYWOOD ADOPTED AS A NAME

The word **plywood** was called into important industrial service during the time of World War I. Up to that time plywood products had been called **veneered** and the process was described as **veneering.** The unfavorable and uncomplimentary connotation of the dictionary definitions of veneer proved to be highly detrimental to the growth and promotion of a rapidly expanding industry. At about this time potential plywood users were increasing rapidly. The makers of automobiles and other motor vehicles, the designers of airplanes, architects and contractors all were attempting eagerly to evaluate the advantages of plywood, then called by its unhappily inherited name of **veneered stock.** Douglas fir plywood from the Pacific Coast was beginning to become available at unbelievably low prices. One of the most difficult handicaps to overcome was the unfortunate public conception of anything that was veneered.

The author well remembers the many strenuous association meetings where the problem was discussed, and the many conferences with the management of the Forest Products Laboratory at Madison, Wisconsin, then a relatively small but important part of the Forest Service of the U. S. Department of Agriculture. After months of consideration and argument the name plywood emerged. It was a truly democratic process of choosing a better and clearly descriptive name for an age-old product, to displace an undesirable title that for years had proved to be a severe handicap to the industry. Plywood had been an obscure word, used to a limited extent in scientific publications and by the few who understood its meaning, but scarcely recognized by the lexicographers. In 1919 the Plywood Manufacturers Association was organized in Chicago, succeeding the old Veneer Association. It was a milestone in the history of the industry, and swept away a serious obstacle to its favorable recognition as a majority industry.

QUESTIONS

1. How far back can the decorative use of veneer be traced, and to what country?
2. How does this early veneer construction compare with the plywood of today?
3. Name and describe the plywood masterpiece of all time.
4. Briefly outline the woodworking-machine developments around 1800.
5. Describe the early form of the veneer lathe and slicer. About when did they originate?
6. What were the two first uses of plywood in pianos?
7. Tell the story of the perforated plywood seat.
8. What was the principal reason for making desk tops of plywood?
9. About when, and for what reason, did furniture manufacturers begin to use plywood?
10. Why are plywood doors superior to those made of solid lumber?
11. What parts of each type of door are of plywood?
12. What was the special characteristic of plywood used in sleigh building?
13. What reason prompted the use of stock panels, and about when?
14. Trace briefly the beginnings of plywood on the Pacific Coast.

SECTION TWO

ADVANTAGES OF PLYWOOD

Economic Considerations

Plywood is a partially fabricated wood product, made of layers of veneer and lumber, intermediate between the raw material—such as the log and the board, on the one hand—and the finished product —typified by the cabinet, piano, chair or bed, on the other. There are definite reasons for using this intermediate product rather than utilizing the unfabricated lumber in the final product.

The cost of a board foot (1 by 1 by 12 inches) in plywood form is more than in solid lumber, due to the labor of cutting the thin layers and rejoining them with an adhesive, as well as to the cost of the adhesive itself. In order to justify this relatively higher cost, the reasons for using plywood must be substantiated either by securing a product that can be made more advantageously of plywood than of lumber, or by finding a way to use less of the plywood than of solid lumber.

Standard Plywood

Conventional plywood consists of an odd number of layers, with the grains of the alternate layers perpendicular to each other. There are many modifications of this conventional construction, as will be described in Section IV. These fundamental advantages of plywood will refer chiefly to this conventional construction, with suggestions as to the effect of various modifications.

Distributed Wood Strength

Normal, solid wood has its predominant strength in one direction, i.e., along the grain; conversely, wood is very weak across the grain and splits easily. If two layers of equal thickness are glued together with alternate grain directions, this predominant lengthwise strength will be distributed in both directions, and will reinforce, in a similar way, the crosswise weakness in the same two directions. As a matter

of practice plywood is ideally made of an odd number of layers, with an equal amount of strength in each direction. A simple example would be outside layers of 1/16-inch veneer and a crossed, center layer of ⅛-inch: 3-ply, all of the same species of wood, as can be noted in Fig. II. 1B, and called an **all-veneer** construction. If different species are used in the layers, the thicknesses may vary according to the known strength factors of each species. Such plywood is known as having a **balanced** construction.

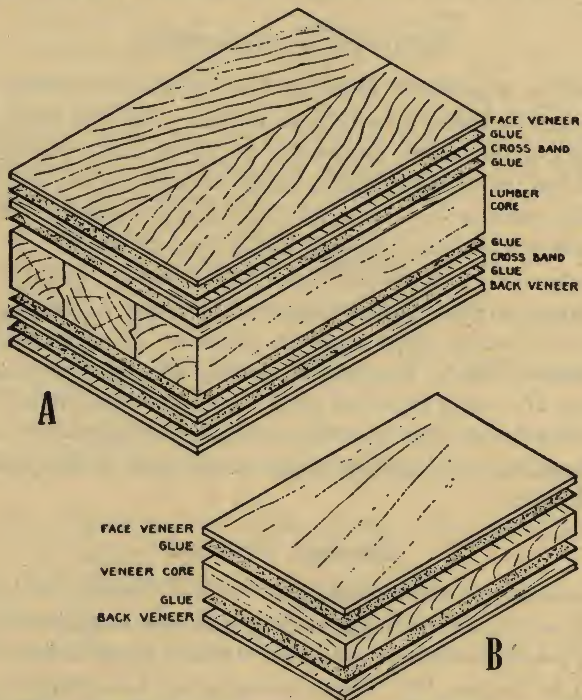


Fig. II. 1—Plywood with layers separated to show the structural features of the different strata.

A—five-ply with lumber core; *B*—three-ply with veneer core. The laminations when glued rigidly together tend strongly to balance the internal stresses and strains and result in a sturdy sheet of compound wood with a rugged base as a foundation for fragile face veneers.

There is considerable latitude in the matter of constructions, depending on the use to which plywood is to be put. There are situations in which a partial balance is more serviceable than a complete balance, an example being the **lumber-core top**, 5-ply construction, where predominant strength is required along the grain of the core, as shown in Fig. II. 1A. In this case the widthwise shrink and swell of the core are restrained by the **crossbands**.

It is also true that considerable strength is added by the adhesive or glue, which must be as strong as the wood, i.e., when layers separate the wood fibres must be torn apart.

All-veneer construction of plywood, with the reinforcing of the alternately crossed layers of veneer, will lack some of the stiffness of solid lumber and lumber-core plywood. However, the distribution of strength usually makes it possible to use much thinner units in plywood than in solid lumber. The pliability of plywood is often an advantage, as in products where curves can be made with plywood that would be impossible in solid lumber.

Non-splitting Qualities

Normal, solid wood splits with comparative ease, especially along the grain in a straight-grained piece. This occurs in driving nails or screws, or when a sidewise strain is put on a nail, screw or bolt, or when it is desired to curve a piece of wood sidewise. The crossed

Fig. II. 2—Non-splitting quality of plywood.
These 40d spikes were driven in a section of plywood floor 2 inches long, without predrilling holes for nails.

layers in plywood make it practically unsplittable, as can be noted in Fig. II. 2, where 40d spikes are normally driven, without preboring, in a piece of ⅝-inch plywood flooring.

This non-splitting quality of plywood is of great value in assembling all types of wood products, in eliminating the boring of most holes, and in permitting the use of nails or other fasteners very close to the ends or edges of plywood.

If the use of nails and other fasteners is left out of consideration, solid lumber tends to split and check as it swells and shrinks under varying moisture content, while plywood eliminates this splitting tendency because of its relative dimensional stability, as is explained below.

Dimensional Stability

The tendency of normal, solid wood to shrink and swell is very troublesome, since it destroys the strength of ordinary mechanical joints and ruins their appearance by opening unsightly gaps and checks. Take the case of a panel enclosed in a frame; if it is of solid wood, swelling may push the corners of the frame apart, or shrinkage may withdraw the panel from its grooves.

Since plywood has half of the wood grain in one direction, and half at right angles thereto, its tendency to shrink and swell is largely neutralized. The shrink and swell of wood along the grain is very slight, almost negligible, and it is conspicuous across the grain, sometimes amounting to as much as 10%. Consequently, plywood has a much greater dimensional stability than solid wood; in fact plywood is practically unchanging in its dimensions, under any usual atmospheric conditions.

Another evidence of dimensional stability is the behavior of plywood in the realm of warping. Solid lumber warps seriously when one surface is exposed to a different amount of moisture than the reverse side. This is actually the result of the normal tendency of lumber to shrink and swell, the wetter surface tending to expand, and the drier surface to contract, resulting in warping and twisting. When plywood is properly balanced, with grain stability in both directions, the tendency to warp is far less than in solid wood. This conclusion, that plywood has only a very slight tendency to shrink and swell, requires some modification when wood grain in the different layers of veneer is angling or curved. However, it should be noted that any wood product with different amounts of moisture on opposite surfaces may give evidence of certain internal stresses which sometimes cause distortion of varying degrees. Plywood made from veneer where its potential shrinking tendency is on a slant, unbalanced plywood, or thin plywood constructions are likely to show some warp, even when properly piled and stored flat.

As a whole, plywood of the proper construction for any wood product will exhibit far less warping than any solid lumber construction. The wide adoption of plywood in furniture, radios, pianos, doors, desks, etc., is ample recognition of this fact.

Availability of Relatively Large Areas

Boards of lumber may be long, sometimes up to 24 feet, while timbers may be as long as 50 to 60 feet, but both are relatively narrow, being limited in plain sawn lumber to the diameter of the log, and, in quarter-sawn, to half that width. Wide, solid boards of maximum log width warp badly, since the rate of circumferential or tangential shrinkage (the width in plain sawn boards) is about double that of radial shrinkage (the thickness in plain sawn boards). As a consequence the practical limit of width in one-inch boards seldom exceeds one foot and will not average over half that.

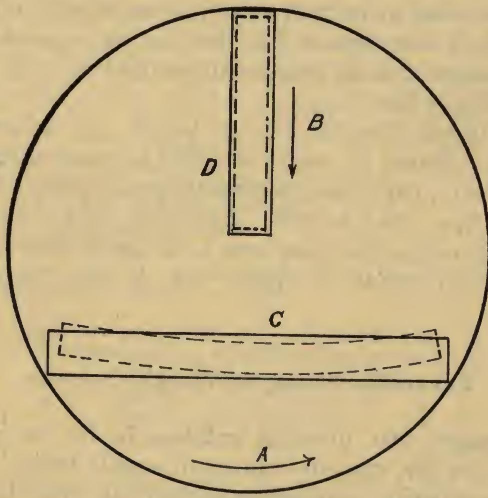


Fig. II. 3—Why plain-sawn boards must be narrow.
A—circumferential shrinkage. *B*—radial shrinkage. *C*—plain-sawn board. *D*—quarter-sawn board.

On the other hand, size limitations in plywood are the length to which veneer can be successfully cut. The majority of veneer lathes will not handle logs over 8 feet long, a few go up to 10 feet, and occasionally to 12 and 16 feet. While sliced and sawn veneer may sometimes exceed these length dimensions, they represent less than 10% of all veneer production, and their use is the exception rather

than the rule in plywood manufacture. There are several reasons why rotary veneer is principally 8 feet and less in length:

1. The longer the log, the larger the core that must be discarded, due to bending tendencies under the pressure of cutting. Expressed differently, the veneer from long logs and small cores will be rough cut in the center, due to inadequate pressure.

2. Long logs have excessive **round-up** waste from the normal growth taper. This rounding-up elimination is necessary to secure a perfect cylinder for cutting veneer.

3. Log imperfections, such as knots, crotches and crooks, greatly reduce the number of long logs suitable for cutting veneer, and correspondingly increase their cost.

4. Long sheets of thin veneer are difficult to handle without breaking. Long sheets of thick veneer impose very heavy power demands on the lathe mechanism. They are clumsy to handle because of the weight of wet veneer.

As a consequence commercial plywood is seldom made with its maximum dimension more than 8 feet. Theoretically plywood could easily be made 8 feet square, but here again, convenient handling becomes a problem, and the maximum standard size is generally considered 8 feet by 4 feet.

While this is less than the normal length of a board of lumber, it is far wider. Hence, for wood intended to cover surfaces such as walls, roofs, floors, partitions, or packing cases, plywood is far more advantageous than solid lumber. Assuming an average board size of 16 feet by 6 inches, the total area is 8 square feet, while an 8 by 4 plywood sheet contains 32 square feet, or four times that of the board.

Favorable Strength/Weight Factors

The advantages that plywood exhibits in its several strength/weight ratios are not easy to express in simple terms, because it is a matter of comparing homogeneous materials with those that are non-homogeneous. The physical properties of metals are quite different in character from those of simple and compound wood. Consequently those with experience and background in metals may fail to grasp the full significance of desirable wood qualities.

Two examples, among several that could be given, may illustrate strength/weight factors in plywood as contrasted with metals, and in reasonably simple form.

Take the question of ultimate **tensile strength,** which in plywood is measured parallel to the grain of the plywood surfaces. The

following tabulation presents **tensile strength/weight factors,** using the specific gravities for weight comparisons.

	Ultimate Tensile Strength	*Specific Gravity Dry*	*UTS/SG*
Normal Plywood			
Birch or Beech	13,200	.67	19,700
Phillippine Mahogany	10,670	.53	20,500
Spruce	5,600	.43	13,000
High-density Plywood			
Birch or Beech	28,500	.97	29,400
Philippine Mahogany	20,000	.95	21,100
Steel, Heat-treated	100,000	7.75	12,900
	125,000	7.75	16,100
	150,000	7.75	19,300
	175,000	7.75	22,600
Aluminum, Various Alloys, etc.	40,000	2.81	14,200
	50,000	2.81	17,800
	60,000	2.81	21,400

It is quite obvious that plywood, under the above conditions, merits a favorable rating with several types of steel and aluminum.

The other example is that of the **stiffness factor,** which is expressed as $E \times I$, and is often called the EI factor. A comparative computation, spruce plywood and metals, reveals the following situation.

$E =$ *Modulus of Elasticity*
$= 1{,}400{,}000$ for spruce plywood
$= 2{,}250{,}000$ for birch plywood
$= 10{,}000{,}000$ for aluminum
$= 30{,}000{,}000$ for steel

$$I = \textit{Moment of Inertia} = \frac{b\ h^3}{12}$$

where $b =$ width $= 1$ in. in all cases
$h =$ thickness at uniform weight of .43 lb. per sq. ft.
$= .153$ in. for spruce plywood
$= .098$ in. for birch plywood
$= .0295$ in. for aluminum
$= .01075$ in. for steel

$$EI = \textit{Stiffness Factor} = E \times \frac{b\ h^3}{12} = E\,\frac{h^3}{12}$$

$$= 1{,}400{,}000\,\frac{.153^3}{12} = 416 \text{ for spruce plywood}$$

$$= 2{,}250{,}000\,\frac{.098^3}{12} = 178 \text{ for birch plywood}$$

$$= 10{,}000{,}000\,\frac{.0295^3}{12} = 22 \text{ for aluminum}$$

$$= 30{,}000{,}000\,\frac{.01075^3}{12} = 3.1 \text{ for steel}$$

The phenomenal advantages of spruce plywood over metals, in the matter of stiffness, are quite outstanding.

It can be observed, from the two examples, that the advantages of plywood over the metals vary according to the particular strength factor chosen for comparison.

Conservation of Timber

The timber resources of the United States are limited and are not being reproduced as fast as they are used. Whether or not their exhaustion is more rapid than that of metal ores is a moot question. It is highly important to develop and maintain the most economical basis of utilization in the timber field.

Log Yields, Veneer and Lumber

It is clear from Fig. II. 4 and the following table that logs, when cut into rotary veneer, give much larger yields than when sawn into lumber. Since imperfections in log quality would be reflected equally in either type of product, the comparison will be fair. Log scales are explained and compared in Table II. 1. This substantial economy in yield is a distinct step in the conservation of raw material, and will extend the life of our timber supply.

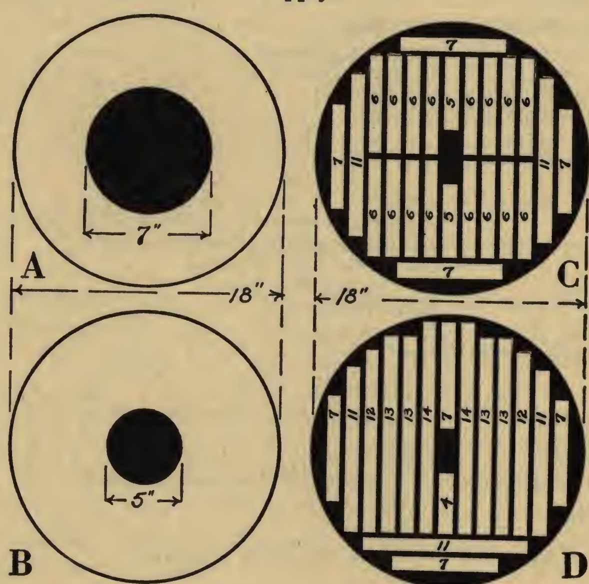


Fig. II. 4—Comparison of yield, 18-inch diameter log. Veneer and lumber. *A*—cut into veneer, leaving 7-inch core. *B*—cut into veneer, leaving 5-inch core. *C*—sawn into lumber, quality basis. *D*—sawn into lumber, quantity basis.

Table II. 1
Yield Comparison, Veneer and Sawn Lumber, by Various Log Scales

Based on Logs, 18 Inch Diameter

	Veneer		Lumber	
	A	B	C	D
Cylindrical Measure				
Total content, board feet	339	339	339	339
Core or waste, board feet	51	26	131	114
Core or waste, percent	15%	8%	39%	34%
Net available product, board feet	288	313	208	225
Net available product, percent	85%	92%	61%	66%
Net Product, by Log Scales				
†Doyle Scale, board feet	196	196	196	196
*possible yield, percent	147%	160%	106%	115%
Scribner Scale, board feet	213	213	213	213
possible yield, percent	135%	147%	98%	105%
Scribner Decimal Scale, board feet	210	210	210	210
possible yield, percent	137%	149%	99%	107%
Spaulding Scale, board feet	216	216	216	216
possible yield, percent	133%	145%	96%	104%
British Columbia Scale, board feet	207	207	207	207
possible yield, percent	139%	151%	100%	109%

From Kent's *Mechanical Engineers' Handbook*, Vol. III, by permission, John Wiley & Sons.

† For log scale tabulations, see pages 119 to 123.

* Computed as follows:

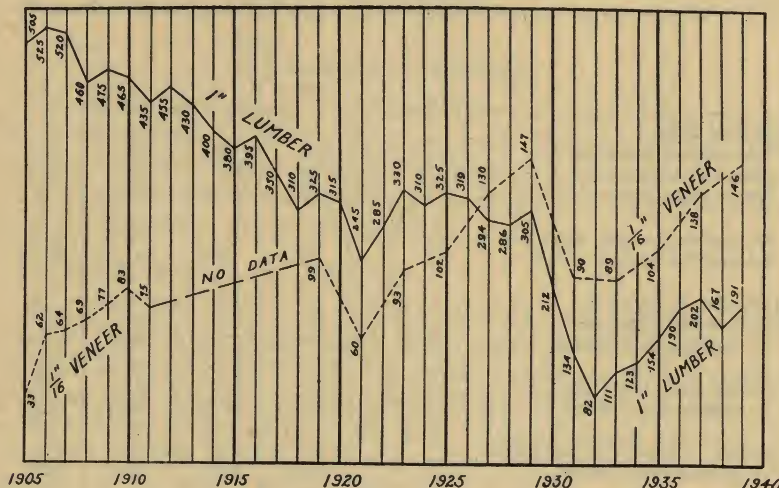
$$\frac{\text{Net Cylindrical Product}}{\text{Log Scale}} = \frac{288}{196} = 147\%.$$

The dark portions shown in Fig. II. 4 are waste, either rotary veneer core, or the allowance that must be made in saw-mill operations for slabbing, ripping off the wany edges, as well as for saw kerf between the boards. This latter, including warping allowance, is usually estimated at ¼ inch. It is also necessary to cut out the heart section, which is nearly always defective.

The 7-inch core is customary in most veneer-cutting operations. Core sizes of 5 inches can only be secured on short bolts, 4 feet and less, and on species that grow with sound heartwood, such as birch.

Logs 18 inches in diameter are chosen as typical. The veneer yield on other diameters is shown on page 47. The lumber yield follows the log scale very closely.

The chart shown in Fig. II. 5 indicates the per capita annual use of veneer and lumber for the last 35 years. Consumption of lumber is reported each year, while that of veneer is biennial.



From U. S. Census Reports

Fig. II. 5—Per capita use of lumber and veneer.

It is apparent that the use of lumber over this period has a distinctly downward trend, while that of veneer is definitely upward. Whether this is due to an intended conservation of material is not wholly clear, but it is, at least, suggested by the facts.

Rotary Veneer Overrun

It was noted in Table II. 1 that the yields in rotary veneer are substantially over 100%, due to the fact that the core waste is considerably less than that caused by saw kerf and wany edges. It was also shown that yields in sawn lumber closely approximate 100%, which is the basis on which log scales were originally established. In veneer parlance, this excess of veneer over lumber yield is termed "overrun," see Fig. II. 6.

A comparative study of this overrun is given in Fig. II. 6 for logs from 12 to 36 inches in diameter. This economy is such that long, sound cores, which are too limber for reduction to a small core, are sometimes cut to shorter lengths, remounted in a smaller lathe while still hot, and cut into thin veneer, thus conserving good quality raw material.

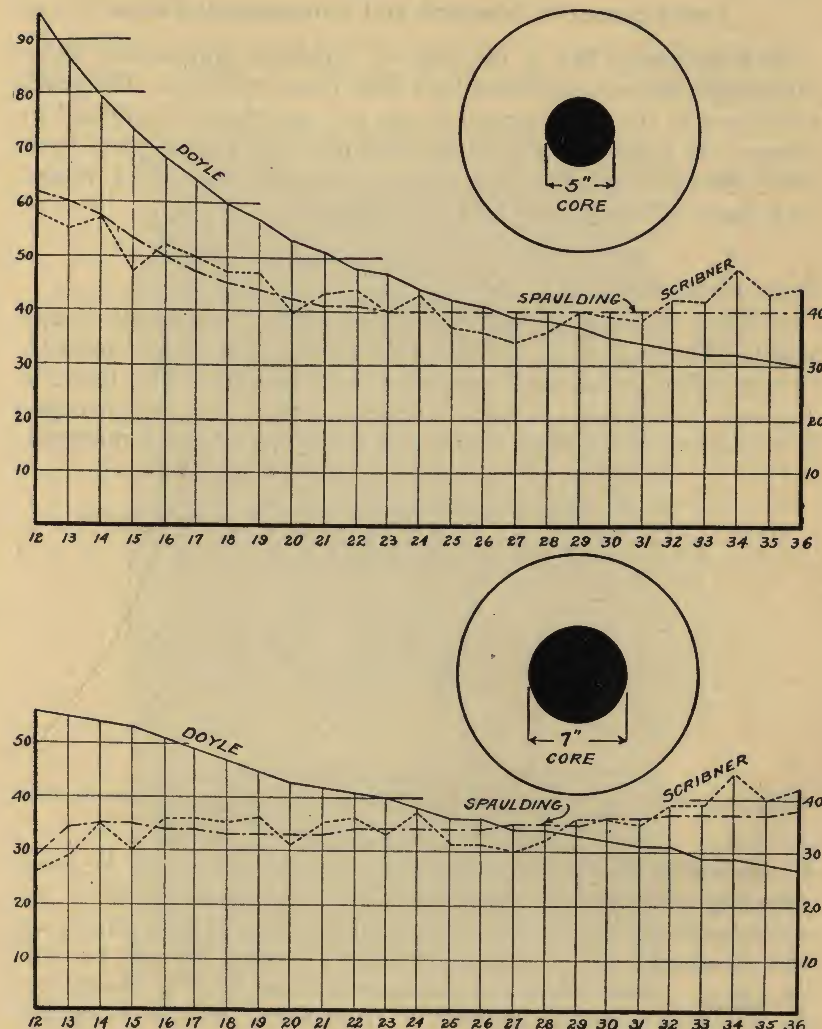


Fig. II. 6—Veneer overrun on 16-foot logs.

Horizontal scale is diameter of logs, vertical scale is overrun above 100%. Charted line is overrun according to indicated log scale, actual core content eliminated before computing overrun.

Development of Matched and Symmetrical Faces

This advantage lies in the field of attractive appearance, while earlier advantages enumerated have been more utilitarian. The grain and figure of the wood appeals to the eye, and should be utilized to enhance the beauty of a piece of furniture. Solid wood parts have their individual appeal to the artistic sense, but the use of veneer encourages a broader expression of beauty.

Book Matching

A single sheet of figured veneer (Fig. II. 7A) is usually somewhat angling in grain effect, and often appears to be "out-of-square." If two pieces are matched together as in B, a symmetrical figure is obtained. Obviously one sheet of veneer is turned over to give opposite effect to the angling grain, and this is called **book matched.**

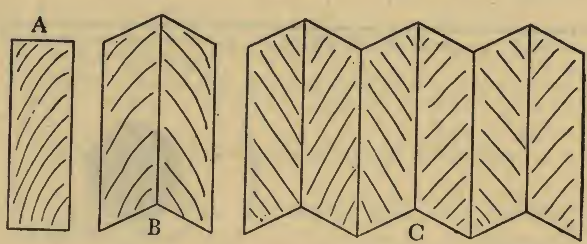


Fig. II. 7—Book-matched veneer.
A—single, unsymmetrical sheet. *B*—two-piece, balanced figure. *C*—multiple book matching.

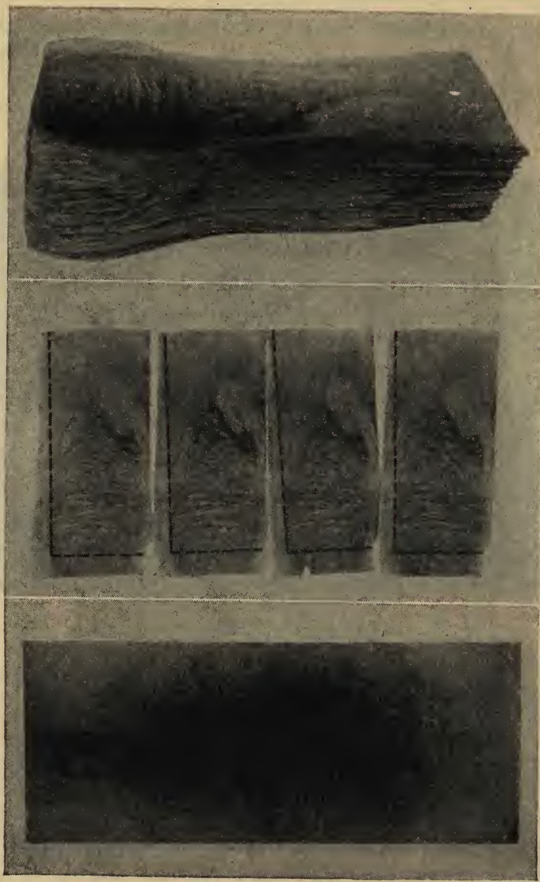
If two widths of veneer are insufficient, three or five may be used, reversing each alternate sheet, as in C. Such balanced effects are unobtainable in solid lumber, as two adjacent boards (boards are not kept in sequence as are veneers) would not present the same or similar figure. Veneer sheets are so thin that neighboring sheets are, for practical purposes, identical in appearance, and can be turned with accurate matching effect.

Slip Matching

Sometimes no attention is paid to matched faces, each sheet being slipped by the other. This is called **slip matching,** while the use of veneers in the illustration is called book matching, i.e., turned like the leaves of a book.

Butt Matching, 4-piece

Another type of matched veneer faces is a 4-piece **butt matched,** from stump veneers, i.e., the lowest cut from a log, including part



Courtesy, A.S.M.E.

Fig. II. 8—Plywood table from stump walnut.

Upper—a flitch of stump walnut sheets piled consecutively as cut. *Center*—four adjacent sheets of veneer, indicating clipping lines for 4-way butt joint with the apex of the dotted lines to be brought together at a central point. *Lower*—complete top, with symmetrical veneer figure, the result of cutting and laying the sheets of veneer shown above.

of the root. This is best shown in Fig. II. 8, in which the method of cutting and assembling is clearly suggested by the caption. In addition to the fact that two adjacent boards, cut from such a stump, would not be alike, there is the further difficulty that such boards

would check, warp and crack in use, due to the twisty nature of the grain. It is this irregular grain that produces the attractive figure that can be enhanced by intelligent veneer matching.

Geometrical and Mechanical Matching

Mechanical matching is also used to a large extent, and a **diamond match** is shown in Fig. II. 9. Many geometrical figures can be made in a similar manner. Marquetry and inlays are often used in such faces, and color contrasts are often quite effective.

Fig. II. 9—Mechanical diamond matching.

It is obvious that only the use of thin veneer makes possible these many types of matching.

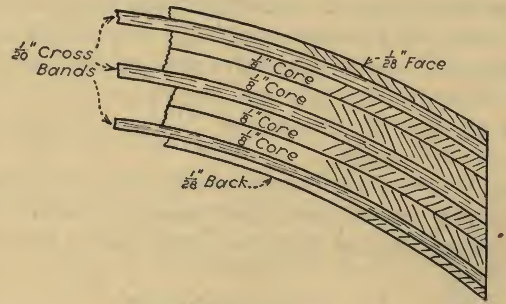
Reinforcing Fragile Veneer

It was pointed out in an earlier statement that solid wood, if of an attractive appearance, is more or less cross-grained, and tends to check and warp in service. If wood of this character is cut into veneer, a cross-section along the grain would show many fibres entering and leaving the wood at sharp angles, resulting in brittleness lengthwise, where normal wood is usually strong. Such veneer is termed **endy** veneer. This severing across the fibres gives depth and character to the appearance of the wood, and adds a darker contrasting color to its effective beauty. This is the feature that is entirely lacking in photographic reproductions of wood figure printed on metal or fibre sheets. These reproductions are usually wretched imitations of genuine wood, without any apparent depth.

Such fragile veneer can be used only when mounted on a reinforcing backing of plywood. Some manufacturers make a practice of mounting such endy wood, by 2-plying, in order to reduce the inevitable breakage in handling and preparing such veneer for plywood assembly. Such 2-ply is ordinarily made with a 1/40-inch birch or maple backing, bonded to the face with Tego resin film in a hot press. The process and product are explained more fully on page 178.

Curved Plywood

The bending of solid wood demands an exacting technique and is quite limited in its scope. Plywood, on the other hand, is admirably adapted to many bending operations. This can be accomplished in several ways. In one method all layers of veneer can be bent before



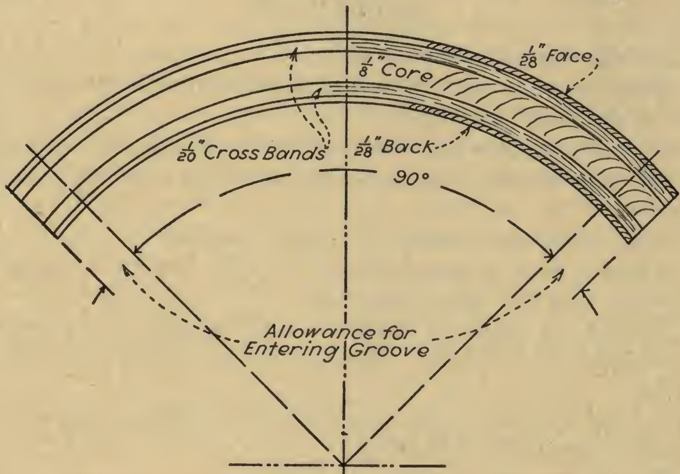


Fig. II. 10—How curved plywood can be made.
Above—typical curved construction, thick plywood. *Below*—typical curved construction, thin plywood.

the glue hardens, the pressure can be maintained by clamping in forms, and as a result the curve will be held rigidly after the adhesive has set and the forms are removed. Two types of such curved plywood are shown in Fig. II. 10. Another method is to machine the lumber base to the desired curve, and apply two or more sheets of veneer around the curve, often using the reverse concave sawn form to apply the pressure. This is, in effect, replacing the saw kerf with veneer. A still further technique is to curve flat plywood between heated rollers, somewhat as steel sheets are curved for tanks, cylinders and boilers. The familiar "Toastmaster" tray of the present time is another example of a wood product that can be made only in the plywood way.

There is almost no limit to the extent that plywood can be curved, if the veneer sheets are thin enough and sufficient care is exercised. While plywood cannot be stretched much, as metal is drawn between pairs of dies, yet plywood boat hulls are coming into general use. Several layers of thin plywood are used, with "V" portions cut away to allow shaping of the bow and the stern. The necessary joints between the plywood sheets and the "V's" are staggered and an amazingly smooth hull results.

Plywood can be made in compound curvatures, and thousands of plywood barrel staves have been made and found far superior to solid oak staves that are likely to rupture under the strain of bending.

QUESTIONS

1. Describe normal standard plywood.
2. What do we mean by the distributed strength of wood, when veneer is made into plywood?
3. Explain why plywood is non-splittable, and its advantages.
4. Tell why the shrinking and swelling of plywood are practically negligible.
5. What is the area relation of plywood and lumber?
6. Describe what is meant by the favorable weight/strength ratio of plywood, and give some examples.
7. Discuss the economic situation with regard to the useful log yield of veneer and lumber. Does it have any effect on forest conservation?
8. In what way does plywood permit the matching of face veneers, and what is meant by that term?
9. Discuss the meaning of endy veneer.
10. How does plywood facilitate curving and bending, as contrasted with solid lumber?

SECTION THREE

ADHESIVES FOR PLYWOOD

NATURE OF ADHESION

Gluing is an ancient art and such a familiar process that it has received little fundamental research to determine, scientifically, why glue sticks? Many theories have been advanced, some of them quite superficial and others suggesting the underlying principles. In the absence of any generally accepted theory that is widely recognized, abstracts of two analyses by competent authorities are presented, in order that the reader may obtain the best current thought on the subject.

Mechanical and Specific Adhesion

One of the oldest and most widely accepted views about the adhesiveness of glue is that it sticks to wood because it gains access, while fluid, to the cavities in the wood structure and then solidifies. The resulting strength of the joint is credited to the intertwining or interlocking of the two strong solids, wood and glue. This can be put somewhat differently by stating that the glue gets its initial grip as it flows from a surface coating into the sub-surface openings of the wood that in a brief period it begins to jell and to become a semi-solid, before it has an opportunity to penetrate too deeply or to diffuse; and that finally the surface coating or film, as well as the prongs or fingers extending into the wood, set or harden, forming a solid of sufficient strength to retain its shape and hold unbroken its many fingers or prongs. This is termed **mechanical adhesion.**

There is no doubt that the above is a correct statement of fact, but it is less than the whole truth. Take, for instance, smooth surfaces, like glass, sheet plastics or polished metals, as contrasted with porous materials like wood. It is well known that such smooth materials can be made to adhere with certain types of glue. It is conceivable that the surface of a dense hardwood, like ebony, can be made approximately as smooth as glass, with a minimum of cavities for the accommodation of the prongs of the adhesive previously mentioned. It is a well-known fact that such smooth wood surfaces can be satisfactorily glued together. It can be demonstrated also that a glue joint between two smooth surfaces can have a much greater tensile

strength than an independent film of the same glue This indicates quite clearly that there is another form of adhesion, which is termed **specific adhesion.** This may be described as surface adhesion, independent of any protrusions of adhesive branches into the surfaces that are glued together.

In the case of adhesion between two pieces of wood, there is known to be a definite combination of both mechanical and specific adhesion. The combination is stronger than either type singly, if it were possible to isolate them entirely. It is interesting to note that the theory of mechanical adhesion is responsible for the use of the toothing planes and scrapers, a long established practice by some woodworkers in gluing such hardwoods as maple.

Polar and Non-polar Forces

Recent research has revealed much additional information about the nature of attractive forces between molecules and atoms, particularly about the secondary forces that exist between them. These secondary forces are of two distinct kinds, called **polar** and **non-polar** forces, which are electrical, although the atoms and molecules themselves are electrically neutral. Liquids can be grouped into polar and non-polar categories; water, alcohol and glycerine are polar, while benzene and paraffine are non-polar. Polar liquids will mix with polar liquids, and non-polar liquids will mix together, but polar and non-polar liquids will not mix. Among solids, metals are non-polar, while wood in its normal state is strongly polar.

These general considerations about polar and non-polar liquids and solids are helpful in understanding the behavior of adhesives. In the case of the use of pure or simple substances as adhesives, there is ample evidence that strong joints cannot be made to polar adherents with non-polar adhesives, nor to non-polar adherents with polar adhesives. This may be considered a basic rule of adhesion. Its application is not simple, since many glues and adhesives are complicated combinations. However, a few examples may help to clarify this basic rule.

1. A phenol-formaldehyde adhesive, such as Tego film, is strongly polar; wood is polar; metals are non-polar. Joints with this adhesive are far stronger between two layers of wood than between wood and metal.

2. Rubber is non-polar, and, in combination with sulphur (also non-polar), can be stuck to metals (non-polar) so efficiently that the rubber will fail under test before the joint appears to weaken.

3. Water is polar, as is wood. Water in solid form (frozen) is an admirable adhesive for wood. If human beings normally could

exist in atmospheres below the freezing point, there would be little use for the many adhesives now on the market.

It should be noted that, while normal wood and its chief constituent, cellulose, are strongly polar yet, when heated under certain conditions, they lose their strongly polar character. Consequently such heated wood absorbs water to a much lesser extent than normal wood, and polar adhesives are less effective. This phenomenon suggests thermosetting qualities in cellulose and wood that resemble those of the thermosetting resin adhesives.

CLASSIFICATION OF GLUES AND ADHESIVES

The glues and adhesives used in woodworking and plywood fall into six principal groups, with several minor types that will be mentioned briefly:

- animal
- vegetable
- casein
- soya bean
- blood albumin
- synthetic resins, phenolic and urea
- miscellaneous

Each has individual characteristics of cost, availability, speed, ease of use, durability, etc., so that there is no one type of glue or adhesive that is superior in all respects to all others.

Since the manufacture of plywood requires the use of glue over relatively large superficial areas, as contrasted with the glue used for edges or intersections in other wood constructions, the cost becomes a dominant factor. As the subject matter of this book relates largely to plywood, these glues and adhesives will be considered in the light of their utility in this industry.

Animal Glues

This is unquestionably the glue of antiquity that has been known ever since man commenced to use wood. There seems little doubt that the pot of glue over the fire in the murals of early Egypt (page 20) contained some primitive form of animal glue that had to be kept melted for use. Due to its long lineage, animal glue has become the accepted standard by which the qualities of all other glues are measured. Some of the older schools of traditional woodworkers refuse to admit that any other adhesives are its equal.

The early animal glues were probably made from the hides of

animals only. At the present time there is considerable diversity in the raw materials, which are divided into two general classifications: **hide-glue** stock, consisting of hide trimmings (cattle, sheep, goat, horse), fleshings, tails, ears, pates, sinews, etc.; and **bone-glue** stock, comprising green bones (direct from packing house and market), and dry bones, either processed to dry quickly or allowed to dry by exposure to the elements. Hide glue is the stronger of the two and commands the higher price. The steps in the manufacturing process consist of a series of washings, liming, acid treatment and steeping in hot water, followed by several cookings. The steps are somewhat more elaborate for hide glue than for bone glue. The first batch, or cooking, gives the highest grades. There is also a wide range in the grade of glue obtained from each class of material. Edible gelatine is a refined variety of animal glue.

The National Association of Glue Manufacturers (animal glue) has worked out and adopted uniform, clearly defined and accurate testing methods, by means of which test results can be duplicated in any suitably equipped laboratory. On the basis of tests of jelly strength and viscosity of the glues, the Association has established a system of grades, numbered 1 to 21. The range of Association grades can be described by the following characteristics:

Grade	*Jelly*	*Viscosity*
18	512	210
10	200	70
4	82	36

The jelly test is the weight required to imbed a standard ball 4 millimeters deep into the surface of the jelly. The viscosity value is in milli-poises. Most of the glues used in woodwork are included in the middle third of this range.

Animal glue may be sold in different forms, of which the cake, flake and ground forms are the most common. Shredded and pearl glues are two forms recently developed. There is no distinguishable difference in strength or other property between these forms.

The grade largely determines the quantity of water to be added in preparing animal glue: for plywood work, grade No. 12 (N. A. G. M.) requires 1 part of dry glue to 3 parts of water; No. 6 requires 1 to 2 respectively, all measurements by weight. As the cold water is added to the dry animal glue the mixture should be stirred thoroughly. The mixture should then stand in a cool place until the glue is completely water soaked, and then the softened mixture should be melted. Shredded glue will soften in a few minutes; ground glue in an hour or less; and caked glue will sometimes take

several hours, according to the size of the cake. The temperature at which animal glue is kept liquid has much to do with its quality. A temperature of 140°F. is usually the permissible maximum, depending on a variety of conditions. At temperatures much below 140°F., decomposition of the glue caused by bacteria or other micro-organisms may set in, and at temperatures higher than 140°F., the deterioration of the glue from chemical action may be hastened.

Since animal glue thickens rapidly as it comes in contact with cool or cold veneer or wood, it is customary to preheat the wood members before the application of the glue. In fact, where animal glue is extensively used the rooms are commonly maintained at temperatures of 80°F., or slightly higher.

The high cost of the better grades of animal glue precludes its extensive use in veneer and plywood operations, but it is still the favored adhesive among skilled artisans for the application of high-grade and highly figured veneer. In the average plywood factory it is largely used for incidental operations, such as edge gluing, repairs and the like.

Animal glue is resoluble in water, after hardening by evaporation and cooling, and is in no sense a water-resistant adhesive. Its water resistance can be substantially increased by using the following formula:

Animal glue	100 parts
Water	225
Oxalic acid	5½
Paraformaldehyde	10

Soak the glue in the water, allow it to soften, melt at about 140°F., all as described above; then lower the temperature to 110°F. Mix the crystals of oxalic acid and paraformaldehyde together and add the dry mixture to the glue, and stir until all of the oxalic acid has gone into solution. The paraformaldehyde does not readily dissolve, but should be kept dispersed in the solution. If the mixture is kept at a temperature of approximately 115°F., it will have a life of from 6 to 8 hours. After two weeks the resulting joints will be reasonably water-resistant in cold water, but not in hot water.

Vegetable Glues

Vegetable glue is the trade term applied by woodworkers to glues made exclusively from starch, a carbohydrate base. Vegetable glues did not come into general use until about 1910 but have been used extensively in recent years because they make strong joints, are

cheap, can be used cold, and the mixtures can be kept free from decomposition and in good working condition for many days. They are impracticable for some uses because they are extremely viscous (cannot be spread with a brush), lack water resistance, and stain certain species of veneers.

The principal raw material used in making vegetable glues is cassava starch, which is obtained from the roots of the cassava, a tropical plant grown mostly in the East Indies. This starch in edible form is more familiarly known as tapioca.

Vegetable glue in its simplest form is made of raw starch, without the addition of any chemicals, but sometimes grades are blended dry to equalize water absorption and viscosity. Some manufacturers make their own importations, at some risk in quality control. A number of plywood manufacturers prefer to obtain their supply of vegetable glue processed. Several methods of processing are in use, some merely blending and adding chemicals, others subjecting the starch to chemical action, followed by washing out or neutralizing the chemicals. Most of these processes are patented.

A properly mixed vegetable glue is translucent, colorless or of an amber shade, viscous and rather tacky. Caustic soda is usually added to vegetable glues to make them stringy and less viscous. The caustic soda also lengthens the working life of the glue, but discolors certain woods, and is sometimes objectionable.

The amount of water required in mixing vegetable glue varies from 1½ to 4¼ parts of water (by weight) to 1 of dry vegetable glue. This wide range of water content depends on the absorptive quality of the starch, the purpose for which the glue is to be used, and the degree of processing to which the starch has been subjected. The high initial viscosity of the mixture makes the use of a mechanical mixer necessary, although this viscosity becomes less as the subsequent mixing steps follow in order.

Most users of vegetable glue prefer to utilize both caustic soda and heat in these subsequent mixing steps, somewhat as follows:

Dry glue and water are mixed cold in a ratio of 1 to 2½ parts, until a thick viscous, but thoroughly mixed condition is reached. Caustic soda, about 3% by weight of the dry glue, is mixed in a small amount of cold water and added to the glue-water mixture. After mixing again, the temperature of the mix is raised by a steam jacket to the temperature recommended by the supplier, stirring continues during the heating, and usually requires about half an hour. The temperature must be carefully controlled, as excessive heat will caramelize the starch, and greatly reduce its adhesiveness. It is an excellent plan to have cold water connections on the steam jacket

to cool off the mixture and prevent overheating. The resulting mixture after cooling is considerably less viscous than the initial mix and can be applied with a mechanical spreader.

Another method of preparation is to use 6% or more of caustic soda which, with thorough stirring, will heat and agglutinate the starch to the desired consistency. Still another option in preparation is to mix the water and starch without caustic soda, relying on the heat of the steam jacket and a longer mixing time to convert the starch into glue of the desired consistency.

After preparation by any of the three methods described above, the mixture is allowed to cool and is ready for removal to storage vats or the spreader. Such mixtures do not deteriorate rapidly and can often be kept several days without apparent loss in strength. When caustic-free glue mixtures become thicker or high-caustic mixtures appear to get thinner, they should not be used. Mixtures by the combined heat-caustic method, first outlined above, usually last longer than these made by either single-step method.

Potato, corn, wheat and rice starches can be used also as the basis for vegetable glues, but have found little favor among woodworkers.

Casein Glues

Casein glues, as now recognized, began to appear in the United States about the time of World War I, when their water-resistant qualities were found to be essential in the development and growth of the airplane program. They had been known and used in Europe since before 1870, but the earlier forms were mixtures of sour milk and quick lime, which had to be used promptly after mixing, and were quite unlike the modern casein glues.

Casein, the principal ingredient of casein glue, is the prepared curd of milk. When obtained as the product of natural souring it is known as self-soured or lactic-soured casein. Also it may be precipitated from milk by sulphuric and hydrochloric acids. The general method of preparation is to remove the acid and other impurities from the curd by washing and then to dry and grind it fine enough to pass through a 20-mesh or finer sieve.

Casein glues are made by mixing water and certain chemicals with the raw casein. They are often referred to as glue cements, because, when allowed to set, they become entirely different in qualities from the original mixture, and most of them cannot be redissolved by water. The main advantage of casein glues is their high water resistance, or ability to retain strength when wet. They are mixed and used cold. The most serious disadvantage of casein glues is their

abrasive quality which exerts a serious dulling effect on edge tools. Other disadvantages are their tendency to stain light-colored veneer, their relatively short working life and their susceptibility to mold and fungi.

Besides casein and water, the third principal ingredient of casein glues is hydrated lime, which reacts with the casein to form a highly water-resistant compound. Different sodium salts are used in various proportions with the lime. Lime content may go as high as 15% of the dry casein by weight, although the average is much less. A properly proportioned mixture of these ingredients will give a strong, water-resistant glue, but it will remain in workable condition only a matter of hours, the higher the lime content the shorter the life. Other chemicals are sometimes added to increase the useful period of the mixture, but their use is largely covered by patents.

Casein glues are classified as **prepared** powders and **wet-mixes.** Prepared casein glues are supplied in the form of a dry powder, containing all the dry ingredients and requiring only to be mixed with water. Wet-mix glues are made up by the user from the several raw materials.

Casein glues must not be heated at any stage of the mixing. Mixing by hand is only possible for small batches, and a suitable mechanical mixer must agitate the mass thoroughly and be much more efficient in that regard than is needed for vegetable glues. The container must not corrode rapidly under the action of alkali (lime) and must be easily cleaned. The short working life of the casein glues makes it imperative that all mixing and spreading equipment be thoroughly cleaned daily.

A **prepared** casein glue is mixed by simply stirring the preparation into cold water, requiring approximately 2 parts of water to one of the preparation, by weight. Some latitude in the quantity of water is permissible, depending on the consistency desired and the kind of work to be undertaken. The water should be poured into the container of the mixer first, with a beater running at about 100 r.p.m. The dry powder should be sifted in slowly to prevent the formation of lumps. After the dry glue has all been added, mixing may be continued at half speed for 15 to 30 minutes until a smooth, thoroughly dissolved mixture of even consistency results.

A **wet-mix** casein glue is prepared progressively. First, the raw casein is stirred in the water as above and allowed to stand for 15 to 30 minutes while the casein absorbs the water fully. Small amounts of caustic soda are sometimes added at this point to facilitate the mixing. The proper amount of hydrated lime is then added,

as well as such other chemicals as may be required to give the necessary working life. After the ingredients are all mixed to a smooth solution, it should be allowed to stand from half an hour to an hour before use.

The working life of mixed casein glues may vary from less than an hour to several days, according to the formula used. Most casein glues become noticeably thicker on standing at room temperatures, but the quality of the joints obtained with such glues appears to be unaffected as long as they can be spread satisfactorily upon the wood. Casein glue mixtures that remain liquid for a day frequently become thinner, generally indicating a deterioration of the mixture, and should be used with great caution. Glue mixtures that will remain liquid, even though used just after mixing, do not produce joints of the highest water resistance.

Soya-bean Glues

These are vegetable-protein glues and originated on the Pacific Coast within the last few years. Peanut meal is also used to a limited extent, instead of soya-bean meal. They are more closely related in quality to the casein glues than to the vegetable (starch) glues, but are used more for Douglas fir plywood and box shooks than for plywood with faces of decorative veneers.

They are mixed cold as is casein, usually with a small amount of caustic soda, and also are combined sometimes with lime. Casein, as a rule, performs more satisfactorily where high water resistance is required. Soya-bean combinations are considerably more water resistant than vegetable glues, and often approach the casein-lime mixtures in this characteristic. The chief advantage of soya-bean glue is its low cost, coupled with a quality that permits the mixture to be spread on relatively wet veneer. Its chief disadvantages are the serious staining that is likely to occur in the use of any type of thin veneer, and the weaker joints that result when soya-bean glue is used on dense hardwoods.

Blood-albumin Glues

Blood-albumin glues were used somewhat in the United States at the time of World War I, but the hot-platen presses required were few and far between, and they did not assume a very important place among the plywood adhesives of that time. They have continued to be used more or less since, but have never become an adhesive of major importance in this country. On the other hand, they are extensively used in Europe and Asia, mostly for low-grade work.

The blood of cattle is usually used for gluemaking. The albumin

is separated from the other substances of the blood, and then dried at a temperature below its point of coagulation. The dark red albumins are generally used in gluemaking.

Blood albumin has the property of coagulating and setting firmly when heated to a temperature of about 160°F., after which it shows marked resistance to the softening effect of water. This characteristic is its chief advantage in the manufacture of plywood. While its initial disadvantage was the requirement of hot pressing, which has now been largely overcome, it still is characterized by joints of low dry strength, by tendencies to foam under active agitation, by the staining of veneers, by odor, and by the fact that so far it has not been practicable to make a dry combination preparation that can be made ready for use by the addition of water.

There are a number of formulas for its use, many of them patented, and both hydrated lime and caustic soda are common ingredients, sometimes one or the other. A satisfactory formula, developed at the Forest Products Laboratory at Madison. Wisconsin, is as follows:

Blood albumin, 90% solubility	100 parts
Water	170
Ammonium hydroxide, specific gravity .90	4
Hydrated lime	3
Water, for dissolving lime	10

Pour the larger amount of water over the blood albumin and allow the mixture to stand undisturbed for an hour or two. Stir the soaked albumin until it is in solution and then add the ammonia while the mixture is being stirred slowly. Slow stirring is necessary to prevent foamy glue. Combine the smaller amount of water and the hydrated lime to form milk of lime. Add the milk of lime and continue to agitate the mixture slowly for a few minutes. Care should be exercised in the use of lime, as a small excess will cause the mixture to thicken and become a jelly-like mass. The glue should be of moderate consistency when mixed and should remain suitable for use for several hours. The exact proportions of albumin and water may be varied as required to produce a glue of greater or less consistency or to suit an albumin of different solubility from that specified.

A formula has been developed for the use of blood albumin without hot pressing, and while the resulting bonds are highly water-resistant, they lack strength and are not uniform. The formula follows:

Blood albumin, 90% solubility	100 parts
Water	140 to 200
Ammonium hydroxide, specific gravity .90	5½
Paraformaldehyde	15

Soak the albumin and water, without agitation, as above for one to two hours, stir slowly, add the ammonium hydroxide and continue to stir slowly. Sift in the paraformaldehyde powder while stirring more rapidly, but sift in at such a rate that neither do lumps tend to form, nor does the mixture thicken and coagulate before the required amount has been added. The mixture thickens considerably, and usually reaches a condition where stirring is difficult or impossible. However the thickened mass will become fluid again in a short time, by standing at room temperature, and will return to a good working consistency in about an hour. It will remain in this condition for 6 or 8 hours, but when the liquid finally sets and dries, as in a glue joint, it forms a hard, insoluble film. When pressed cold it has only moderate dry strength, but if hot pressed it will show excellent strength properties.

One of the problems in the use of blood as an adhesive is its limited penetration. Because of this, developments are under way which indicate that blood may become an important ingredient, when combined with other adhesives, such as the resins.

Synthetic-resin Adhesives

Resin adhesives for woodwork are of recent development, and had hardly graduated from the laboratory stage in 1930. Their use developed slowly in the United States until 1935, when synthetic resin adhesives of domestic manufacture became commercially available. Since that time their growth has been rapid. At the present time their cost, availability and durability appear to establish them in a position where they are likely to displace most of the other conventional adhesives in operations where volume production will justify the installation of the necessary equipment. The growth of the plastics is one of the marvels of modern industry, and resin adhesives, being members of this plastic family, have derived much momentum from this association.

The resins chosen for adhesive uses, while initially in water solution, when properly polymerized, become insoluble, and non-resoluble in water. Hence their unusual water-resistant qualities are the result of this transition from solubility to insolubility through the medium of polymerization under simultaneous heat and pressure. This polymerization is a phenomenon similar to vulcanization in rubber or coagulation in albumin. The better known term, polymerization, is used in this text to express the cure of resins. The correct chemical term is condensation.

Hence, it is evident that the resin-adhesive program required the use of hot presses which had been used first for blood-albumin glues,

although the resins demanded higher temperatures and specific pressures than had been customary with the albumin glues. Up to 1941, over 125 hot presses had been installed in various branches of the woodworking industry, indicating quite clearly that the use of resin adhesives has become permanently established as an integral part of the plywood industry.

It should be noted that, while the resin adhesives established their initial characteristics of unusual durability in the hot-press process, more recent developments have resulted in reagents or catalysts that will accomplish polymerization at room temperatures. However, so far the cold-press resin process does not afford the economy, speed or durability of the hot-press procedure.

There are two principal types of resin adhesives, the **phenol formaldehyde** and the **urea formaldehyde**. Since the technique of their use and their resulting qualities differ substantially, they will be described separately.

Phenol Formaldehyde

This first became commercially important as an impregnated paper or film in the early 1930's and made substantial progress in Europe before it became established in the United States. During those early years, while it was imported from Europe, the high cost of importation prevented any extensive use, until domestic supplies began to become available in 1935.

Phenol-formaldehyde resins are synthetic materials derived from products that are domestically available. The film is made by impregnating a very thin tissue paper with a water solution of phenol formaldehyde, drying it and supplying it in continuous rolls ready for use. It weighs about 12 pounds per thousand square feet, of which about one third is paper and two thirds resin. It can be stored safely for a year in a cool, dry place.

Its advantages fall into two classes: **First,** its extreme durability, since it is boilproof, can be soaked indefinitely, and in weather exposure will outlast the wood. Its boilproof quality permits steaming for softening in bending and forming operations. Its durability is also expressed in resistance to mold and fungi growths, a characteristic possessed more markedly than in the other glues heretofore described, most of which definitely encourage mold development. **Second,** its ease of application; the plywood manufacturer is relieved of all the complicated and untidy operations of mixing and spreading, and merely has to dimension the sheets of the film and interleave them with the layers of veneer. It is difficult to spread any liquid adhesive on veneers thin-

ner than 1/30 inch, so that the use of a film is the only practical means of utilizing the very thin plywood required in aircraft construction. In fact the resin-film adhesives bid fair to be a major factor in re-establishing the use of plywood in aircraft.

Its chief disadvantage is the need of carefully conditioned veneers, since a slight residual moisture must be in the veneer to assist in the initial flow of the resin just as it is exposed to the simultaneous action of heat and pressure. It is not well adapted to use on rough and loosely cut veneer.

The hot-pressing (at 280° to 300°F.) operation requires a matter of minutes, and the plywood is complete and ready to dimension as soon as it cools. This contrasts with the two- or three-day cycle required in cold pressing, for initial set in clamped bundles and subsequent redrying to remove the surplus moisture added when the liquid glue is applied.

Liquid phenolic adhesives are also available, but are only in limited use. Their use reassigns to the plywood manufacturer the problems of mixing and spreading, and hence lacks the efficiency of the film.

Liquid phenolics can be combined with other ingredients to a limited extent, but this technique has not, as yet, progressed very far on a commercial scale.

Dry-powder phenolics are also offered, to be mixed and applied as are the liquid phenolics. The advantage of the dry powder is longer storage, with safety, than is possible with liquids.

There are developments in progress along the line of combinations of phenolic-resin liquid adhesives (including the dry powders) with other reagents to polymerize at room temperatures, or at oven temperatures around 150°F., but as yet they have been used on a very small scale, and cannot be considered as suitable for general adoption.

Urea Formaldehyde

Along with the development of hot-press technique and the growing use of phenol-formaldehyde resin film as a plywood adhesive, there came an insistent demand from the industry for a resin adhesive with a wider field of usefulness, lower in cost and not requiring such high temperatures of polymerization. It was admitted that the desired resin might require the more complicated application of a liquid rather than that of a film, and that it might fall somewhat short of the durability of the phenolic type, but broader use would compensate for this. The resulting product appeared as a urea-formaldehyde resin, similar in adhesive qualities to the phenolics, but derived from a quite different source. These resins were

made available in both liquid and dry-powder form, and would polymerize at temperatures between 225° to 250°F. Their outstanding characteristic, in which they differed from the phenolics, was their capacity to accept extenders, relatively inert in adhesive character, like wheat flour, that would reduce the cost, with some progressive lessening in quality and durability. As the further development of these urea adhesives proceeded on a practical scale in a number of leading factories, it became apparent that the cost of this new adhesive closely approached that of the better grades of vegetable glues, and still retained a definite superiority in water resistance and durability over animal, vegetable, casein and soya-bean glues.

It is too early to predict how rapidly and how far these new urea-resin adhesives will displace the group of earlier adhesives that have been described, but it is evident that the plywood industry is going through a transition period, with strong leanings toward a wider adoption of urea-resin adhesives for many kinds of plywood.

The liquid urea-formaldehyde adhesives usually have 60 to 70% concentration of solids, and require the addition of a catalyst to accelerate the process of polymerization. When used without extender, they show a tendency to penetrate wood too rapidly, and maximum results are obtained by adding an extender equal to 20 to 35 pounds of wheat flour per 100 pounds of liquid resin.

A few typical formulas follow, all measurements being by weight:

	A	B	C	D
Liquid urea resin......	100 parts	100 parts	100 parts	100 parts
Extender, flour	70	100	150	200
Water	60	100	150	200
Catalyst, liquid	8	8	8	8

Formula A is suitable for high-grade cabinet work, while D is most suitable for such items as drawer bottoms, and dust backs where service and durability are not paramount.

The process of mixing is to put water in the container, add the liquid resin, stir to a smooth milky solution, add the flour slowly to keep the lumping at minimum, and stir until the mixture is smooth and free from lumps. The water or flour content may require slight adjustment, depending on flour absorption, up or down, to secure the desired consistency. All mixing is done cold, and the catalyst is added and stirred in a few minutes before the batch is required for use. The same type of mixer can be used that has been described as employed for casein. It is important that all equipment be thoroughly cleaned at least once a day. When the higher flour ratios are used it is essential that the resin and extender be uniformly dispersed throughout the entire mixture, continuing the time of stirring

up to half an hour or more. Mixer paddles should be equipped with extensions so that no amount of material can accumulate on the inner surfaces of the container.

Urea resins are also available in dry-powder form, without extender, in which case the above formulas are altered by reducing the quantities in the top line to a solid base, i.e., in a 70% concentration, change the 100 to 70. The remaining 30 pounds of water are added to the quantities in the third line. The second and fourth lines of the formula remain unchanged. Otherwise the procedure is the same as in the case of the liquid ureas. Dry ureas are more stable in storage than are the liquid forms.

A third type of urea-resin adhesive is in dry-powder form, with a dry form of catalyst, combined in a dry mixture by the supplier, and only requiring the addition of the water and extender. A variant of this third type is when the extender is also added by the supplier, but in such cases the purchaser should ascertain the durability of the mixture. Such combinations, with catalyst included, must be kept dry in storage, to avoid premature catalytic action.

Urea resins of certain types can also be provided with catalysts that will polymerize at room (70°F.) or oven temperatures (100°-150°F.). Their use requires several hours in clamps, a more liberal initial application of adhesive, and sometimes a redrying of the surplus water introduced into the wood with the adhesive. It is obvious that factors of cost, time and factory floor space favor the use of the hot-press types of urea-resin adhesives.

There is increasing interest in melamine-formaldehyde resins, which are similar to the urea resins, but are characterized by better water resistance and have a high degree of boilproofness. They have definite promise in the low-temperature field, when they become available commercially.

Miscellaneous Adhesives

Silicate of Soda

This is a form of liquid glass and finds considerable use in the paper and boxboard industry. All sodium-silicate solutions are odorless, colorless, and will not encourage mold or fungi growths. It is used in about a 40% solid concentration, spreads well and makes a strong joint, not however the equal in strength of animal glues. It is reasonably stable in solutions, but dries hard and brittle. Its chief use in the plywood industry is for box shooks, where its initial and moderate water resistance is an advantage. Its chief disadvantage, and the reason that it is so little used in better ply-

wood, is that it deteriorates on exposure to air, and plywood made from sodium silicate will weaken after one or two years of exposure. At the present time it has been largely displaced in the plywood shook industry by vegetable and soya-bean glues.

Fish and Bladder Glues

These types constitute a large percentage of the liquid packaged glues sold over the retail counters. They are made from the heads, bones, skins, trimmings and swimming bladders of fish, somewhat as animal glue is derived. A few of these liquid glues are made from animal glue and an acid reagent, and there are some other minor sources. They have not been standardized but, in general, thick glues give stronger joints than thin solutions, and a good test is a glue that remains workable while in the container, but sets quickly after application.

Their place in the plywood industry is minor, chiefly for small, odd jobs and repairs, and they are only included for the sake of completeness.

QUESTIONS

1. Describe what is meant by mechanical adhesion and specific adhesion.
2. What is the polar and non-polar theory of adhesion?
3. Under what conditions is wood polar?
4. What are the principal types of plywood adhesives?
5. From what is animal glue made, and what is the general process?
6. What is vegetable glue? What are its principal advantages?
7. Describe the methods that can be used in mixing vegetable glue.
8. What are the advantages and disadvantages of casein glue?
9. For what kind of product are the soya-bean glues used mostly?
10. Name and describe the two principal types of resin adhesives.
11. To what type of work are the phenol-formaldehyde resins best adapted and why?
12. Discuss the differences between the urea- and the phenolic-resin adhesives.

SECTION FOUR

CHARACTERISTICS OF MODERN PLYWOOD

PLYWOOD QUALITIES

Plywood qualities depend on the particular construction employed. It may be designed for beauty, for durability, for stiffness, for strength, for lightness, for cheapness, or for many other qualities. With an infinite variety of constructions to choose from, there is a wide range of differing characteristics. Among the most conspicuous qualities are those of appearance, of strength, and of capacity for bending and molding.

In fact it may be truly said that the versatility of plywood gives to wood products the same facility to adjust physical characteristics that is imparted to metals by the many metallurgical processes of alloying and heat treatments. As in the field of metals, it is often possible to accomplish the same ultimate results in plywood by different methods or processes. The practical procedure in either field will often be determined by the availability of the raw materials, the accessibility to manufacturing equipment, the experience and skill of the workmen, and last but not least, by the factors of cost.

Hence, this outline of the fundamentals may serve as a guidebook to those who are traveling forward in the plywood field, or to those who are expecting to undertake projects where plywood characteristics need to be understood.

Plywood for Beauty

This element of attractive appearance was the first motive in the use of thin layers of wood, or veneer, in ancient Egypt (see pages 20-1). Thin sheets of attractive species of wood were combined with inlays and overlays of metals, precious stones and other materials. This motive still remains an important factor in the design and use of plywood. Different species of wood have different colors, vary in texture, and have a wide range of what is termed characteristic grain figure. Straight-grained, plain cut, white and English

oaks have a beauty all their own and are associated with the Gothic styles. The use of mahogany suggests many designs of the furniture periods. Maple and birch are typical of the early American Colonial styles.

Opportunities for beauty selection result from several methods of cutting the same log. Oak, for example, may be plain cut, quarter sawn, or express an intermediate type of figure with a character of its own, unfortunately called a bastard cut. Other species such as maple may grow straight grained, or logs may have a bird's-eye figure, or show a curly grain. These several maple varieties in turn may be cut by various methods and add to the varieties of figure within a single species. American black walnut not only permits the cutting methods mentioned for oak, and includes the types of growth indicated for maple, but adds the crotch, burl and stump growths. The crotch occurs either at the point of junction of twin branches or may come at the junction of any large branch. Nature interlocks, interweaves and criss-crosses the wood fibre to give the necessary added strength at a point where wind and storm would be most likely to damage the tree. It was noteworthy that trees with broken crotches in the great New England hurricane of 1938 usually showed signs of decay in the crotch. The crotch has a feathery and curly beauty that adds attractiveness to plywood designs and constructions. A more moderate crotch figure, usually cut from the outside (rather than the center) of the crotch, is called a swirl. The burl is an excrescence that grows like an enormous wart on a tree, rather globular in form, and yielding a relatively small sheet of veneer, studded with eyes and concentric figure surrounded by deep-colored, endy wood. A stump growth is near the root, developing partly above and partly below ground. The interwoven fibre here is again nature's protection against the elements, firmly anchoring the entire tree structure in the ground. The grain appearance bears some resemblance to the crotch, except that many large roots from all directions combine together to form the trunk, as contrasted with two branches that make a crotch.

The grain effects that occur in relatively straight-grained logs may be cut into either lumber or veneer, although the sequential character of adjacent grain figure in veneer affords the possibility of matched faces. On the other hand, crotches, burls and stumps have such a twisty grain that, from a practical standpoint, they can be cut only into veneer. Solid lumber boards from such growths would warp and check to such an extent as to be of limited practical value.

Some species, such as sweet gum, have an attractive heartwood figure that comes only from quarter cutting. Its crotch and stump

growths have little if any veneer value. Redwood has a distinctive burl growth and cypress yields remarkably beautiful burls and crotches, but otherwise they have no artistic veneer values.

It is thus seen that the designer of wood products to be made of veneer and plywood has at his command an almost endless variety of wood figure and grain that may be combined in an infinite variety of ways. Colors are also available for artistic effects, from the white of holly to the brownish black of ebony, from the yellow of boxwood to the deep brown of walnut, from the pink of mahogany to the brilliant shades of vermillion wood, and rosewood has its own characteristic purples.

Plywood for beauty, therefore, can combine nature's lavish growths, cut in several directions by various mechanical processes, into the ultimate reaches of beautiful appearance that result from the consumate skill and judgment of the experienced designer.

Plywood for Strength

It has been shown in many other connections in this book that plywood distributes elements of wood strength in various directions, as may be required in a given wood product. Here the species of wood and the direction of the cut do not depend on appearance, but on ultimate strength factors. In general, a quarter-sawn board is more stable (i.e., shrinks and swells less) than a plain-sawn board, since in most species, tangential or circumferential shrinkage is about double that of a radial cut. (See Fig. II. 3.) Sliced or sawn veneer has fewer checks than rotary cutting, and may be slightly stronger, and considerably more resistant to warp than rotary veneer. Heartwood, or the center growth of a tree trunk, is more dense and usually harder than the sapwood near the bark of the tree. In general, sapwood is more resilient and lighter in weight than heartwood. Trees of the bamboo family are exceptions to this rule, with the most dense wood on the outside.

Strength in plywood may be evidenced in several ways. Stiffness is desirable in column loading; limberness, in plywood that is to be curved or bent. Plywood that is to be preformed into curves during the bonding operation must be stiff after the adhesive has secured its grip. Plywood for flooring or partitions must be equally strong in all directions. In airplane construction it is highly important that the ratio of strength to weight be favorable. In some cases, such as beams under bending loads, the upper and lower surfaces, as of an "I" beam, require adequate resistance to tension and compression, while the central part requires bulk rather than strength since the

portion adjacent to the neutral axis requires far less resistance than the top and bottom.

Still another use of certain types of plywood, for an airplane propeller blade, requires high density near the hub, where fastening devices demand maximum bolt-holding power, and at the same time as low a density as possible near the tip, where centrifugal forces at high speeds are a serious problem. This may be accomplished either by scarfing two pieces of a different species together, or by exerting much higher bonding pressures on the plywood at the hub end than at the tip end. Other types of plywood, such as flooring, require a hard and wear-resistant surface, while the inner layers merely furnish a supporting foundation, and are subject to no direct wear. In the textile industry a picker stick that reverses the shuttle motion at each stroke must have dense and durable portions where the shuttle comes in contact, with resilience and elasticity in the shaft between the wearing parts.

One of the factors in plywood strength is the number of layers, since it is obvious that plywood ¼ inch thick is considerably stronger when made of 1/50-inch veneer than when made of 1/12-inch. There will be more layers and the strength factors are more evenly distributed.

Many plywood constructions, such as a table or desk top, must have their dominant strength in one direction: lengthwise. To assure this, it is customary to use a lumber core with grain running lengthwise (parallel to the faces) and to use relatively thin veneer for the crossing, face and back.

Engineers who are studying to obtain maximum strength factors in plywood have a wide opportunity to secure the strength required, and often several methods are available. As in the case of metal alloys, it is possible to design and predict the strength distribution in plywood by adjusting the species, grain direction of the layers, thickness of the veneers, pressure, and other known variables.

Plywood vs. Laminated Wood

Alternate cross-laid sheets of veneer are the fundamental characteristic of plywood, since this construction distributes the lengthwise strength of wood in each direction, and thus reinforces the adjacent widthwise weakness. Obviously a comparison of a piece of plywood 1 inch wide by ½ inch thick with a piece of solid wood of the same size and species would show certain differences. The normal plywood would be more limber, while the solid wood would be much stiffer. It would be easy to split the solid wood, and almost impossible to split the plywood. The shrinkage and swelling of the

solid wood would be normal, while that of the plywood would be negligible.

Consequently, if stiffness is essential in any location where solid wood is not desirable, and where some type of built-up wood is preferable, it will be advisable to use parallel layers which will be even stiffer than solid wood, due partly to the presence of the glue layers, and partly to the fact that the continuity of the wood grain is broken up by the independent layers.

Veneer glued together in parallel layers is more correctly called **laminated wood** than plywood, and usage is strongly favoring this distinction in name. There are cases where occasional cross layers, every fifth or tenth, will impart to laminated wood the qualities of non-splitting and stability of dimension.

Wood with parallel laminae is a more usual construction in lumber and timber utilization than in the general field of thin plywood. Many types of timber arches and trusses are laminated, since the lapping and staggering of the ends of the individual layers permit far longer laminated timbers than can be secured in solid timbers.

There may be many variations in the angularity of the veneer layers in plywood, such as a progression of 15° or 30° angles in successive layers, where strength must be more uniformly distributed than with the grain of the layers at their normal position of 90° apart. An example is silent gears of plywood, where wood grain parallel to the radial tooth line is an important strength factor.

Still another variation in normal plywood is where a 45° angle is used in the face veneers, and the cross layers are at right angles to the face grain, or at 45° in the next quadrant. This is especially applicable to spar covering in aircraft design, a type of hollow-beam construction where the major stresses are best balanced in this way.

Many of the problems of gluing and assembling are very similar in normal plywood and laminated wood, where both are made of veneer layers. The differences are largely those of direction. Hence, it is quite customary to make both products in the same plant, using the same material and processes.

However, for the sake of clarity, the term **laminated wood** is best reserved for constructions with all the layers substantially parallel, while **plywood** best describes veneer constructions in which the layers have varying degrees of angularity.

Plywood for Curving and Bending

Typical and normal plywood constructions are more limber, and therefore bend or curve more readily than solid lumber of the same thickness. Wood has a tendency to compress more easily sideways

than it does lengthwise, hence the resistance to bending in plywood occurs more in the veneer layers where the wood fibres are bent than where these fibres are pushed together or stretched apart sideways.

As plywood technique has progressed from its original right-angle (90°) relation of the adjacent layers into the bending and curving field, constructions have been altered gradually until now many special layer arrangements are recognized.

Curved construction is often made of 2-ply, in which the grain of the thicker layer is parallel to the axis of the cylinder of curvature. Ordinary 2-ply has a decided tendency to warp and twist, but designers can often use this tendency as an aid in attaining the desired curves.

Where curves are quite sharp, with short radii, an inner layer at 90° may tend to break, and experience shows that the inner layer at 45° is much safer to use. A curve, that would ordinarily bend the normal transverse crossing into a segment of a circle, with 45° crossings will become an oval, obviously lessening the stress of the bend. This 45° construction is often used on pilasters in radio cabinets.

There are many other combinations of veneer layers to facilitate the making of curves out of flat plywood. The important consideration in such designs is to reduce the leverage that tends to rupture the veneer on the convex side, and to use such thickness, species and grain direction as will yield most readily to the pressure of curvature on the concave side. In all these constructions it is important to have the layer adjacent to the face at some substantial angle thereto (30° and more), so as to provide enough reinforcement to protect the face veneer from rupture in any direction.

An aid to bending or curving is wetting or steaming at the point of curvature, but in such cases the adhesive must be of such a type as to prevent delamination under such treatment.

The problems that occur when veneer is formed into curved plywood during bonding are described on pages 51 and 84.

TYPES OF PLYWOOD CONSTRUCTIONS

The number of plywood constructions is almost endless, considering the available species of wood, the many thicknesses of veneer and lumber that are used in the various layers, the angular arrangement of the adjacent layers, the types of adhesives with their qualities, the degree of pressure exerted and the resulting compression of the wood; and these are only some of the major variations. Another

complication in these varieties is what is known as combination faces, where several species of veneer may be arranged in one layer for contrast, and grain directions may be altered to enhance this effect. Still further the construction of lumber cores, within the lumber-core layer, may be designed for different utility effects: cut-outs for typewriter desk tops, windows in plywood doors, lattice cores for reducing door weight, banded (or railed) cores to eliminate end-grain exposure, and many others. While many types of plywood are known in industry, new combinations are constantly appearing and further developments are in progress.

The major divisions that are recognized are listed herewith and briefly described:

All-veneer construction—This includes a large majority of plywood constructions, but the term is used particularly to designate "top" construction (5/8 to 1 1/4 inch) made of an aggregate of veneer layers, as contrasted with lumber-core construction.

Lumber-core construction—This is based on the use of a lumber core, to give predominant strength in one direction. In regular 5-ply constructions the face veneer and the core have parallel grain directions, so that the appearance of this plywood and solid wood in a piece of furniture would be similar.

Two-ply constructions—While such constructions are not normally balanced, they serve a number of special uses, such as reinforcing faces, wall coverings, elements of curved constructions, and the like.

All-veneer Constructions

This fundamental plywood type, where the use of several layers adds the plywood qualities, as contrasted with solid lumber, has been elsewhere described (page 38). In plywood designed for strength, it is customary to select the better and clearer grades of veneer for the faces, and the less desirable grades for the inner layers. For ultimate economy it is customary to use veneers of the same thickness in all layers, providing standard thicknesses will make the ultimate required total thickness, with better grades outside and poorer selections inside. This procedure utilizes the whole of the log, as it is cut into veneer, and eliminates the necessity of lay-backs that have to be worked over into other veneer and plywood products. Lay-backs are a serious problem in every veneer plant, since the cost of reworking them is often as much as the value of the material.

It sometimes happens that uniform thicknesses will not work out, and it becomes necessary to use thicker inner layers, often of an inferior species, or one that has predominant strength qualities.

In many cases the all-veneer construction is used as a matter of economy and expediency in factories where facilities are not available for making lumber cores. In general, this all-veneer construction is somewhat cheaper than the same total thickness with lumber cores, and is not so highly regarded for furniture construction as is the lumber-core type. There is some reason to feel that the all-veneer construction is more likely to warp than the lumber-core construction. However, this tendency can be largely neutralized by the veneer-slitting operation described on page 137. Another method of reducing this tendency to warp is the use of thinner veneer, providing the additional fabricating cost does not stand in the way.

There are a number of variants in all-veneer constructions, such as 3 layers of 3/16-inch veneer, which will practically take the place of the lumber core, and then the usual crossbanding and faces, resulting in a 7-ply product. Some manufacturers make this 3-ply, 9/16 inch as a preliminary or intermediate stock item, adding the crossbands, faces and backs when customers' specifications are received. This results in a two-stage gluing operation. Others make the entire 7 plies in one gluing operation.

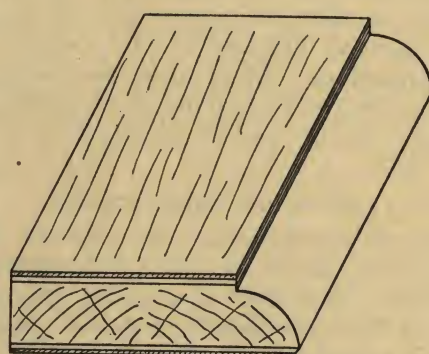


Fig. IV. 1—Molded edge on plywood.
Lumber-core construction preferable, as all-veneer construction would display a zebra-like effect.

There are several products in which all-veneer construction is preferable to plywood with lumber cores, such as die-cutting blocks of maple, where successive layers can be planed off to provide clean cutting surfaces, until the block becomes too thin to be of use. Examples of other industrial plywood uses are: silent gears where the successive layers are at 15°, 30°, 45°, or other angular ratios; pairs of forming dies for shaping thin metal; multi-ply constructions for textile spool ends and shuttles; pin planks for anchoring tuning pins

in pianos; thick cushion plates for mounting motors and machinery to reduce the transmission of vibration, etc.

In general, all-veneer constructions are preferable to lumber-core constructions where relatively large radius bending is to be undertaken, such as in boat and shipbuilding, where curvature may be required for hull planking, crowned decking, bulkheads and hatches. Such gradual curves are often made out of flat plywood, but may be bent in forms as the layers of veneer are glued together.

If plywood edges or ends are to be molded, or are conspicuous, the all-veneer construction may be objectionable, as compared with the lumber-core construction, as can be noted in Fig. IV. 1.

It is important that designers and engineers study their problems and adapt the plywood construction to the service required.

Lumber-core Constructions

The origin of this type of plywood is not entirely clear, but it was first used in furniture parts in the 1890's. The change to plywood gave two distinct advantages over the solid wood that had been used up to that time: shrinking, swelling and warping were greatly reduced; and beautiful, but fragile face veneers could be used safely when reinforced with supporting layers of plain but sturdy veneer and lumber. Solid wood of the same figure character was wholly impractical to use. A type of semi-plywood, i.e., a face veneer glued to one side of a curved lumber part, like a buffet or sideboard door, had been used on many classical designs of furniture, but it was not true plywood where the element of balanced construction and the reinforcing of crossbands were utilized for stability. It did, however, express the idea of a sturdy lumber back for a fragile face veneer.

There are many types of lumber cores, from the plain strip core to the intricate lattice-work interior to reduce weight and improve the insulating qualities of an apartment door.

The better grades of lumber-core plywood are made in 5-ply, since it provides more adequate balance, and the parallelism of the core and face veneer makes for consistently better appearance and strength, since it conforms to the conventionality of grain direction in such items as solid doors, to which the public had become accustomed long before plywood doors came into use.

The use of 3-ply lumber-core construction is usually a compromise with cost factors, requiring a more perfect core, since slight core defects may be apparent through the face veneers. In general, most types of lumber-core constructions can be made in 3-ply, providing the following factors are duly evaluated. While the 3-ply will be

cheaper, it will not be so sturdy, will warp more readily, will sacrifice appearance, and will have the grain direction of the core at right angles to that of the face veneer, which is often a structural handicap.

Plain Lumber Cores

The simplest form of lumber core is that made with random width core strips glued edge to edge. These may be ripped slightly tapering, to eliminate defects, and should not be over 3 inches wide, to reduce the tendency to warp. Adjacent strips that are ripped apart should be turned or reversed to prevent the accumulation of warping tendencies. The straighter-grained strips, obviously, should be used for outside edges.

A modification of this type of core is the use of standard-width strips, usually 2 and 3 inch, which are ripped on a gang saw to secure uniform widths. In such cases short strips can be butted together endwise, using material more economically and reducing warping and twisting tendencies that might occur in long strips. Both of these types of lumber cores are illustrated on page 142.

Banded or Railed Cores

There are many types of plywood utilization in furniture and similar products, where exposure of end wood in a core is objectionable. It is difficult to get smooth cutting on end wood, and the open

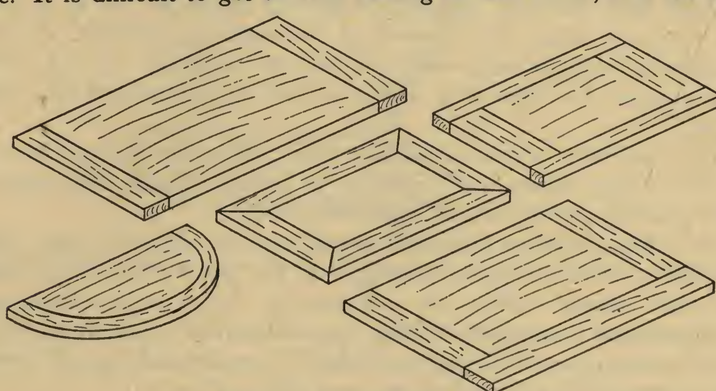


Fig. IV. 2—Banded lumber cores.
Bands or rails reduce the exposure of end wood and facilitate uniform finishing effects.

pores absorb more filler and pigment and take on a deeper color than side grain wood finished in the same way. This difficulty can be overcome by the use of rails or bands across the ends of the core

strips, giving side-wood exposure all the way round, except at the ends of the bands. Even that can be obviated by mitered corners on the rails, which is a complicated and expensive procedure that is seldom used.

Several types of railed or banded lumber-core constructions are illustrated in Fig. IV. 2.

It is to be noted that special types of railed constructions are available for semi-circular tops, either a bent rail curved like the felloe of a wheel, as shown, or angular bands across the ends of the core strips, which afford practically no end grain exposure (Fig. VI. 6G, page 142).

In the better grades of lumber cores the rails or bands may be of the same species as the face veneer, thus exposing only that kind of wood by which the piece of furniture may be described for sales purposes.

In the case of a desk top, with hinged section for typewriter compartment, the rails may be inside, rather than at the ends of the core, as shown in Fig. VI. 6H.

Still a different type of construction for desk tops is described as having concealed crossbands. In this case the lumber cores and crossbands are first glued together and trimmed. The rails, which are of the same species as the exposed veneer on the desk top, are narrow, often tongued and grooved into the 3-ply inner section, mentioned above, and mitered at the corners as shown in Fig. IV. 3.

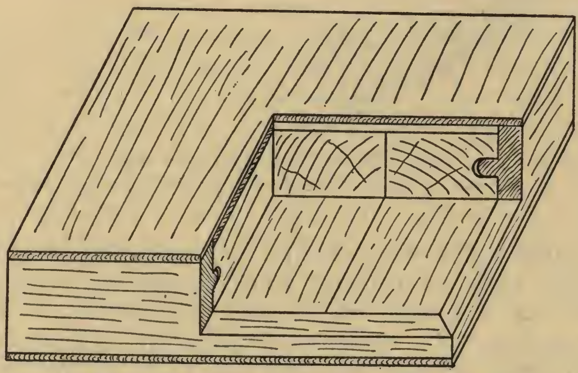


Fig. IV. 3—Concealed crossbands on desk tops.
Special construction for improved appearances. Requires gluing in two stages or steps.

The face veneers are glued on as a separate and subsequent operation, after the making of the 3-ply core and the application of the rails.

Door Cores

There is a wide range of plywood constructions used in doors of various types, from the simple conventional door with plywood panels and solid stiles and rails, to the flush door made like a desk top.

A door construction of better quality than that with solid lumber stiles and rails is made with 3-ply stiles and rails, in which the grain direction of the outer veneer and the lumber core are parallel, as shown in Fig. IV. 4. In this case the two outer edge strips of the lumber core are of the same species as the face veneer and the panel to be inserted. The center of the core is usually of the small pine blocks described later for the standard flush door. Thus, when the edges of the 3-ply members are trimmed and molded, there will be only one species of wood visible.

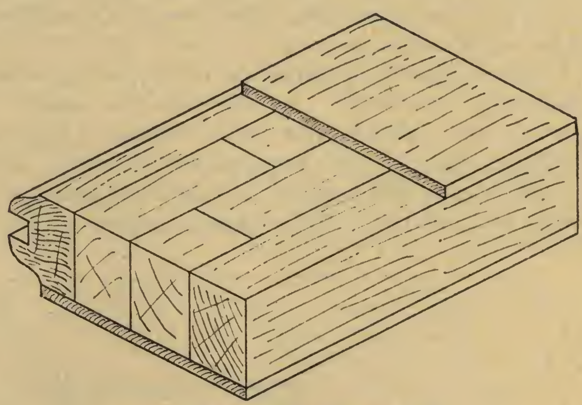


Fig. IV. 4—Laminated door rail.
While not conventional plywood construction, it is made by normal plywood processes.

The standard flush door, favored for use in schools and hospitals, is usually a 5-ply construction, with conventional faces and cross-bands, but has a special core of small pine blocks (shown in Fig. VI. 6D, on page 142). These small blocks are surplus cuttings from the manufacture of sash and solid door parts, as short as 6 inches and seldom over 24 inches long. They are usually approximately square, but are cut to maximum available width to assemble into the core, and surfaced off, after core is completed, to the necessary thickness for a 1⅜- or 1⅞-inch door. These door cores are railed or banded along the two edges by continuous strips of the same

species of wood as used on the veneer face. Before these edge rails are attached, end rails are put on the top and bottom of the door core, particularly to protect the pine-core blocks from water absorption, either weather exposure on the top, or drawn up from a wet sill or floor below. Doors of this construction are unusually free from warp, due to the small size of the core blocks and the consequent wide distribution of normal wood stresses.

Another style of flush door, intended especially for interior use, has a more or less hollow center in the core, of a honeycomb or type box form, as illustrated in Fig. IV. 5.

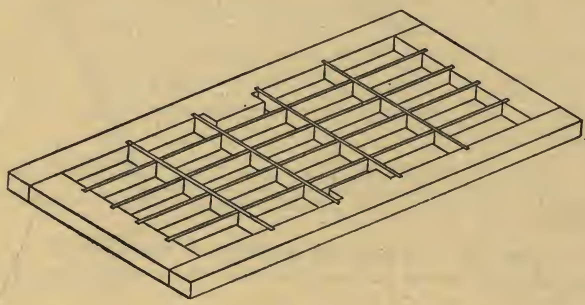


Fig. IV. 5—Hollow core for flush door.
Partitions may be of wood or fibreboard.

This type of door is very light, is reasonably sound deadening, and has adequate edge strips in the core to accommodate hinges and mortise-lock hardware. In its construction 3-ply panels are first made in a separate operation, and then glued to the lattice-type core. These lattice strips may be of half-inch lumber, or in some instances of similar sized synthetic fibreboard material.

There are still other types of hollow-core flush doors, where stile and rail construction is provided for the core, and 3-ply panels are used for covering both sides. This type of hollow door has a tendency to be resonant and the plywood may become slightly concave where it is unsupported.

Most of these types of flush doors can be made with inner layers of metal or asbestos for fire resistance, or with lead linings for X-ray rooms in hospitals.

Flush doors can be also made with concealed crossbands, as described above for desk tops, except that the corners of the rails are not mitered (see Fig. IV. 6).

Reinforced Faces and Two-plying

While a 2-ply construction is not stable and is in no sense a balanced plywood type, it has many uses both as an intermediate and sometimes as a final form, resembling normal plywood in many particulars.

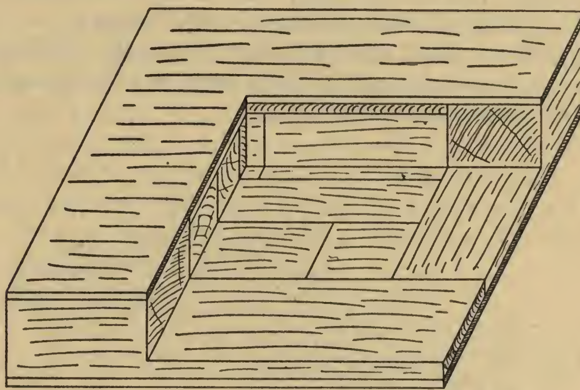


Fig. IV. 6—Concealed crossings in flush doors.
Vertical edge rails are continuous and cover the ends of the horizontal top and bottom rails.

Strengthening by Two-plying

Fragile face veneers, such as highly figured stumps and crotches, burls and the like, are difficult to handle singly without excessive breakage. Manufacturers of veneers frequently reinforce them with a backing sheet of plain sturdy veneer, such as 1/40-inch birch or maple. The grain direction of the backing is usually at right angles to that of the face, although some prefer parallel laying. In any event the backing should be laid for the purpose of reinforcing the face in whatever form it is to be subsequently used. This reinforcing is sometimes done in flitch form before dimensioning and matching, then again, after the faces have been matched and taped. The latter plan is often followed in the case of "swelled" drawer fronts, buffet doors, curved bed ends and the like, where single-ply fragile faces would be likely to rupture in bending. In the case of sharp bends on small radii, the backing is sometimes laid at a 45° angle with the face to ease the bending stresses. Film adhesives are preferable to any form of liquid adhesive for this work, as the latter are too prone to penetrate throughout the faces.

The same reinforcing procedure is sometimes used with ordinary face veneers (non-fragile) that are to be bent around small diameter pilasters.

Aircraft and Boat Multi-ply

There are instances where several successive layers of 2-ply plain veneers are used to make the leading edge of an airplane wing, or to supply the hull planking on a small boat. These are usually 2-plied flat in a hot press, then steamed to soften, curved, dried and assembled in a pressure-bag apparatus, to produce a stiff enough curved piece to withstand severe service stresses. This process is fully explained and illustrated on pages 186 to 190, and on page 234.

Molded Trays

Trays furnished with domestic toasting sets are often made of 5-ply construction. The faces and backs are both 2-plied to give the sturdiness necessary to stand the stress of molding. After a preliminary preforming, these 2-ply outsides are bonded against the center layer of thicker plain veneer into the final molded shape required.

Plywood barrel staves are similarly 2-plied on the outsides, but have a larger number of inner layers to make up the required thickness.

Wall Coverings

There are a number of types of 2-ply reinforced veneer used as wall coverings, and applied like wallpaper. The best known of these, "Flexwood," is made of 1/80-inch veneer, flexed and glued to a cloth backing. The flexing treatment is so thorough that Flexwood can be bent without breaking around a ¼-inch radius. There are several other types, with kraft-paper backing or sheet-rubber backing. Most of these wall coverings are made in long narrow strips, the width of a sheet of face veneer, and of a length to reach the height of the room.

Cedar Chest Two-ply

This construction comprises a face veneer of standard thickness (1/28-inch) applied directly on cedar lumber built up like a lumber core. In that way the exterior of the chest may be designed to match furniture of any species and style, while the interior preserves the effect of cedar lumber. While such a construction lacks the stability of ordinary 5-ply, it can be built into a cedar chest with lock-corner joints that will have all necessary stability. The same type of construction is used for cedar lockers or wardrobes. The grain of the face veneer and cedar lumber can have such directional relations as may be desired for appearance.

Fabrication for Simple Bending

Some of the veneer and plywood constructions required for this type of work have been anticipated in the description of 2-ply above, where the influence of the 2-ply is wholly to protect the face veneer from rupture.

When the thickness of such simple curved members becomes sufficient to require several intermediate layers of veneer, it is customary to lay them all with grain parallel to the axis of the cylinder around which the bending is done. In many cases all central layers are parallel, next to the outer and next to the inner layers are very thin with opposed grain, while the grain of the exposed veneer is again parallel. Such constructions would be appropriate for buffet doors of all-veneer construction, or for segments of cylindrical textile rollers and drums. (See Fig. II. 10, page 51.)

It has been pointed out that a 45° angle direction is often employed for the normal crossband in sharp bends.

One of the underlying principles in making curved plywood is that there must be adequate pressure at the sides of the curves.

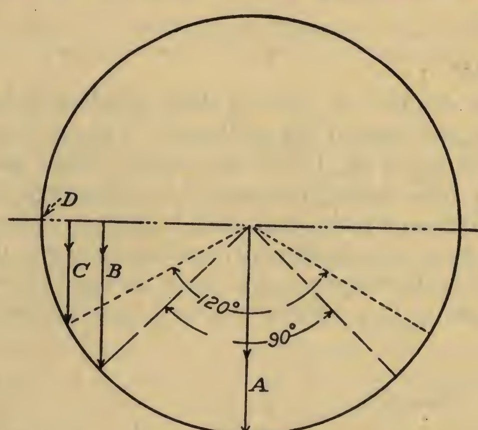


Fig. IV. 7—Pressure diagram.
Indicating distribution of vertical pressure for various size segments.

This can be illustrated in Fig. IV. 7, where the ordinary vertical pressure will be effective in the middle 90° marked *A*, and is likely to be inadequate beyond that point, as at *C*, where the component of pressure in a vertical direction would not insure sufficient contact between the veneer layers to secure a strong bond.

If the pressure is obtained by the flexible-bag method, see page 186, this angular limitation will not be effective.

Compound Bending and Molded Shapes

This includes constructions where the curvature occurs in two directions, as in a barrel stave. While metal will draw or stretch to form a cup or a pan or a dipper, wood possesses this characteristic to a much smaller degree. In general, wood will compress more safely than it will stretch, and the thinner the layers and the softer the wood texture, the more compression can be secured. However, as in the case of the barrel staves, there is a definite limit to the width of stave that can be made without rupture of the veneer under tension, or a lapping and piling up under compression.

It is sometimes possible to cut out "V"-shaped pieces from the veneer to prevent such lapping, but this too often complicates the work more than is justified.

The technique of compound curvature in plywood is in a formative stage, and the fluid pressure effects made available with flexible bags promise substantial advances in the practice of making compound curved plywood. (See pages 186-90.)

Molding plywood into compound curvature recognizes the "draw" imitations of wood and substitutes—hence, the use of narrow strips of veneer, cut to such pattern shapes as will fit snugly together around curves without overlapping. In some instances, these veneer strips are woven, basket-wise, for temporarily holding their curved shape until the adhesive becomes effective after the pressure is applied. It is apparent that these successive layers of narrow strips may be laid in various angular grain relations, depending on the direction in which the particular curvature can be accomplished best with a minimum of strain on the veneer.

When such layers are approximately at right angles to each other, it is often called a **geodetic** arrangement. This is an aviation term, said to be due to the resemblance between this design and the aerial photographs of landscapes, where the checkerboard effect of roads and section boundaries is most pronounced.

If such compound curvature becomes shell-like in shape, it is often called **monocoque** construction. Such monocoque shapes have remarkable strength characteristics, due to the distributed strength qualities of plywood. Adequate data on their design is very limited. When braces or stiffeners are added in this shell construction, it is called **sėmi-monocoque.** It is predicted that the further development of such shell constructions will broaden substantially the field of plywood utility.

STANDARD STOCK SIZES VS. SPECIAL CONSTRUCTIONS

The earlier types of plywood were usually made to a size, thickness and construction that were suited to a special purpose—somewhat of a custom-made basis. Not until the early 1900's did the standard stock panel begin to make its appearance. It was partly to provide plywood for structural uses, where sizes were large and relatively uniform, but also to supply a standard stock for such manufacturers as would find it convenient to carry on hand large sizes ready to cut down into smaller sizes when required.

The advent of Douglas fir plywood, about 1920, added emphasis to the structural utilization of low-cost plywood in large sizes.

Stock panel sizes have gradually increased until 4 by 8 feet has become the generally recognized standard, on which the price structure is based. Smaller sizes usually enjoy slight differentials downward, while larger sizes are distinctly more costly, due to the difficulty of securing large clear veneer faces, and the greater complications of manufacturing and handling such oversize material.

While there have been marked progressive changes in stock panel standards, at the present time they appear to have become fairly well stabilized. This is due to the fact that their marketing has been largely consolidated in a single organization, the United States Plywood Corporation, which has made a long continued and careful study of customers' requirements and has established warehouses from coast to coast, backed by ample manufacturing facilities in the various plywood producing areas.

It is obviously out of place to try to describe in detail the various constructions and grades that are available, but an outline of the sizes, thicknesses and species will afford a perspective view of what the market offers to users of stock panels.

In general the grades of the exposed faces are termed good (above which there may be a number of higher classifications for appearances); **sound** (with minor regard for appearances, but with major emphasis on serviceability); and **reject** (allowing various defects on one side that do not impair its utility for certain purposes). In general the inner layers are not specified, and are allowed to be made according to the option of the plywood manufacturer.

The following tabulations (Tables IV. 1, IV. 2 and IV. 3) give the major classifications that are representative of what can be obtained.

Table IV. 1

Stock Panels, Standard Constructions and Sizes

Douglas Fir Plywood, Standard Grades, Good, Sound 1 Side and 2 Sides.
For Wallboard, Sheathing and Other Unexposed Purposes.

Sizes Width x Length	*Thickness and Plies*									
	1/8″ 3-*ply*	3/16″ 3-*ply*	1/4″ 3-*ply*	5/16″ 3-*ply*	3/8″ 3-*ply*	1/2″ 5-*ply*	5/8″ 5-*ply*	3/4″ 5-*ply*	1-1/8″ 7-*ply*	1-3/16″ 7-*ply*
24″ x 48″	....	....	+	....	+	....	....	....	....	....
60″	....	....	+	....	+	+	....	+	....	....
72″	....	+	+	....	+	+	....	+	....	....
84″	....	....	+	....	+	+	....	+	....	....
96″	....	....	+	....	+	+	....	+	....	....
30″ x 60″	....	....	+	....	+	....	....	+	....	....
72″	....	+	+	....	+	+	....	+	....	....
84″	....	....	+	....	+	+	....	+	....	....
96″	....	....	+	....	+	+	....	+	....	....
36″ x 60″	....	....	+	....	+	....	....	+	....	....
72″	+	+	+	....	+	+	+	+	....	....
84″	+	+	+	....	+	+	+	+	+	....
96″	+	+	+	....	+	+	+	+	....	....
120″	....	....	....	....	....	....	....	+	....	....
48″ x 60″	....	....	+	....	....	....	....	+	....	....
72″	....	....	+	....	+	+	+	+	....	....
84″	....	....	+	....	+	+	+	+	....	....
96″	+	+	+	....	+	+	+	+	+	....
108″	....	....	+	....	....	....	....	....	....	....
120″	....	....	+	....	+	....	....	+	....	....
144″	....	....	....	....	....	....	....	+	....	....
60″ x 54″	....	....	....	....	+	+	+	+	....	....
108″	....	....	....	....	....	+	+	+	....	....
Douglas Fir Sheathing, No Face Requirements.										
48″ x 96″	....	....	....	+	+	+	....	+	....	....
Douglas Fir Concrete Forms, Water Resistant, Sound 2 sides.										
48″ x 96″	....	....	....	....	....	+	+	+	....	....
California Pine Plywood, Standard Grades, Sound 2 sides.										
24″ x 60″	....	....	+	....	+	....	....	+	....	....
72″	....	....	+	....	+	....	....	+	....	....
84″	....	....	+	....	+	....	....	+	....	....
96″	....	....	+	....	+	....	....	+	....	....
30″ x 60″	....	....	+	....	+	....	....	+	....	....
72″	....	....	+	....	+	+	....	+	....	....
84″	....	....	+	+	+	+	....	+	....	....
96″	....	....	+	....	+	+	....	+	....	....
36″ x 60″	....	....	+	....	+	....	....	+	....	....
72″	+	....	+	....	+	....	....	+	....	....
84″	....	....	+	....	+	....	....	+	....	....
96″	....	....	+	....	+	....	....	+	....	....
120″	....	....	....	....	+	....	....	+	....	....
48″ x 72″	....	....	+	....	+	....	....	+	....	....
84″	....	....	+	....	+	....	....	+	....	....
96″	+	....	+	....	+	+	....	+	....	+
120″	....	....	+	....	+	+	....	+	....	....

+ Indicates available standard sizes.

Table IV. 2
Stock Panels, Standard Constructions and Sizes

Hardwood Plywood, Standard Grades, Good 1 Side and 2 Sides.
Birch, Walnut, Maple, Mahogany, Oak and Other Species.

Sizes *Width x Length*	*Thickness and Plies*					
	1/8″ 3-*ply*	1/4″ 3-*ply*	3/8″ 5-*ply*	1/2″ 5-*ply*	5/8″ 5-*ply*	13/16″ 5-*ply*
24″ x 48″	....	+	....	....	....	....
60″	....	+	+	....	....	+
72″	+	+	+	....	....	+
84″	....	....	....	....	....	+
30″ x 48″	....	+	....	....	....	....
60″	....	+	+	....	....	+
72″	+	+	+	....	....	+
84″	....	....	....	....	....	+
96″	....	....	....	....	....	+
36″ x 48″	....	+	....	....	....	....
60″	....	+	+	....	....	+
72″	+	+	+	+	+	+
84″	....	+	+	....	+	+
96″	....	+	+	....	+	+
48″ x 72″	....	+	+	....	....	....
84″	....	+	+	....	....	+
96″	....	+	+	....	....	+
72″ x 36″	....	....	....	....	....	+
144″ x 28″	....	....	....	....	....	+
36″	....	....	....	....	....	+
42″	....	....	....	....	....	+
48″	....	....	....	....	....	+

13/16″ hardwood plywood made with lumber cores.
+ Indicates available standard sizes.

Table IV. 3
Stock Panels, Standard Constructions and Sizes

Waterproof Plywood (Phenolic Resin), Various Face Grades.
For Sea and Aircraft, Also for Weather Exposed Uses.

Species and Sizes Width x Length	*Thickness and Plies*										
	1/16″ 3-*ply*	1/8″ 3-*ply*	3/16″ 3-*ply*	1/4″ 3-*ply*	1/4″ 5-*ply*	3/8″ 3-*ply*	3/8″ 5-*ply*	1/2″ 5-*ply*	5/8″ 5-*ply*	3/4″ 5-*ply*	7/8″ 5-*ply*
Birch											
36″ x 72″	....	....	....	+	....	....	....	....	....	....	....
48″ x 84″	....	....	....	+	....	....	....	....	....	....	+
96″	+	+	+	....	+	....	....	....	....	....	+
Mahogany											
48″ x 96″	+	+	....	....	+	....	....	....	....	....	....
Poplar											
48″ x 96″	....	....	....	....	+	....	....	....	....	....	....
96″ x 48″	....	....	....	....	+	....	....	....	....	....	....
Walnut											
36″ x 72″	....	....	....	+	....	....	+	....	....	....	....
48″ x 96″	....	....	....	+	....	....	....	....	....	....	....
Plain Oak											
48″ x 96″	....	....	....	+	....	....	....	....	....	....	....
Douglas Fir, exterior grade											
36″ x 72″	....	....	....	+	....	+	....	+	....	+	....
96″	....	....	....	+	....	+	....	+	....	....	....
48″ x 96″	....	+	....	+	....	+	....	+	+	+	....
120″	....	....	....	+	....	+	....	....	....	+	....
144″	....	....	....	+	....	+	....	+	....	+	....
192″	....	....	....	....	....	+	....	....	....	....	....

+ Indicates available standard sizes.

PLYWOOD WITH TEXTILE, FIBROUS AND METAL LAYERS

Various combinations of veneer, plywood and laminated constructions can be made, using one or more layers of non-wood material. As these different materials vary considerably in their physical characteristics, the technique of their assembling is treated separately according to groups of similar materials in the following order:

Wall Coverings, with Cloth or Paper Backings
Cloth Veneer Combinations
Veneer Paper Combinations
Fibreboards, Masonite, Celotex, Insulite, Homasote, etc.
Asbestos Veneer Combinations
Plaster and Gypsum Boards
Plywood-metal Sheets

Wall Coverings

Genuine wood interiors have always been highly prized, but in many cases existing conditions, such as size, shape, cost or time, prevent the ideal solution. These problems can often be solved by the use of a special reinforced veneer wall covering that closely resembles plywood. Very thin sheets of veneer are backed by cloth or paper and can be applied much as wallpaper is hung. These reinforced veneers may be long narrow strips, such as sheets of longwood (page 140) from a flitch of veneer that gives the desired characteristic figure, or they may be combination veneer faces mounted on a piece of cloth or paper. The best known of these types is **Flexwood,** which has a veneer face, about 1/80 inch thick, glued to a rather thin cotton cloth. The veneer is first passed through a series of rolls, which render it very flexible by bending or flexing the fibres without breaking them. This flexibility, with a cloth backing, permits making as sharp bends as would be required to encase an ordinary lead pencil. This veneer-cloth combination can be applied to walls, columns, ceilings and other architectural members, much as wallpaper is put on walls. Proper adhesives can be used in hanging to give satisfactory results on wood, plaster, metal, fibreboard or any other smooth and stable surface.

Another type of wall covering is reinforced with a kraft-paper backing and developments are in progress toward spraying on a thin rubber coating that gives the necessary toughness to the veneer and prevents splitting.

These combination materials are often used for wall coverings in auditoriums, offices, lobbies, banking rooms and libraries, frequently

with wood trim and plaster walls. The result is an attractive interior where perhaps all wood and plywood construction would be impractical. It is also used to provide wood interiors in lightweight streamlined trains, planes, busses and the like, where it must be applied directly on metal.

Cloth-veneer Combinations

Other cloth and veneer assemblies are employed in more utilitarian ways, where the woven fabric may supply extreme flexibility and the veneer produces the desired surface as well as the degree of stiffness required. Examples are conveyor belts, guard cages on dangerous machinery, special packing devices and the like. Cloth and veneer can be glued together with most of the adhesives elsewhere described (pages 53-68), but with thin cloth backing it is important to guard against the penetration of the adhesive through the cloth. Measures to prevent this are thick mixtures or a waterproofing of the cloth.

Cloth may be the central layer between two sheets of veneer with parallel grains, providing great flexibility in one direction. Cloth-faced plywood with resinous adhesives has been used to a limited extent for plywood houses, providing an excellent painting surface for exterior or interior.

Veneer-paper Combinations

Veneer and kraft-paper combinations are receiving recognition in a number of industrial fields. Paper has a grain, along the length of the web as manufactured, although the contrast between "along the grain and against the grain" is far less conspicuous than in veneer. Paper is relatively stronger across the grain than veneer, and hence can be used to reinforce the weakness of the veneer. Plywood with paper centers or paper outsides are both in use, and various constructions give differing results. Paper, unless treated with special water-resistant binders, tends to delaminate more rapidly than veneer in the presence of moisture. Hence adhesives must be chosen and applied to penetrate as deeply into the paper as possible without going through to the opposite side of the paper.

Veneer-paper combinations are used for packing cases, for dust bottoms and mirror backs in furniture, for partitions in cabinets and similar uses. They may be very flexible where curved or angling partitions are essential, as in radio and phonograph cabinets.

Fibreboards

There are a number of well-known types, such as Masonite, Celotex, Insulite, Homasote, which in general bear some resem-

blance to very heavy paper. **Masonite** is made from pine chips that are shredded by an explosive process; **Celotex** is chemically produced from the fibres of bagasse, or sugar cane stalks; **Insulite** fibres come from chemical processes that separate the wood fibres much as is done in paper making, except that the fibres are much coarser; **Homasote** is a conversion of old newspapers into fibre form that permits reaggregation into a fibreboard. These various fibres, by whichever of the above processes produced, are all made into thick mats on equipment that resembles those used to make paper. These mats are rolled and pressed dry to the desired density.

The fibres are progressively floated out into enough layers to make the bulk required, but the fibres themselves are essentially parallel, so that the resulting board is somewhat stratified. As a consequence most of these boards can be separated into layers with comparative ease, and have a distinct difference in stiffness between the length, parallel to the fibres, and the width, perpendicular to them. These various boards have excellent strength qualities and may be dried and pressed into various thicknesses and densities for different industrial and structural purposes. They may be machined and fabricated much as plywood is handled. Their appearance, however, lacks character, and when used in conspicuous locations, they must be painted or treated to blend more attractively into their surroundings.

One of the recent developments is to face them on one side with thin (1/30- to 1/60-inch) veneer, obviously a construction that is not wholly balanced, but one that still meets many practical requirements, when such boards are adequately supported at ends, edges and sufficient intermediate points.

The adhesive technique required in attaching veneer to these boards, converting them into 2-ply, is somewhat different from the normal plywood processes. One layer, the veneer, is relatively hard and dense with fibres closely knit together, while the other layer of **low density** fibreboard is very porous with fibres that are not thoroughly bonded together. The requirement of the adhesive is that it must penetrate the veneer sufficiently to get a good grip without going through, and at the same time penetrate deeply enough into the fibreboard so that the outer layers do not strip off. Some difficulties are likely to occur in meeting such diverse requirements, and it is often helpful to size the fibreboard with a dilute adhesive, which is dried before the final bonding operation. This sizing penetrates the fibreboard more deeply than the normal adhesive, holding the layers of fibres together, and subsequently reduces the absorption or penetration of the normal adhesive. This duplex

method gives good bonds when properly done. As the original pressure under which these low-density fibreboards are manufactured seldom exceeds 30 to 40 pounds per square inch, great care must be exercised not to crush and destroy their porous insulating character.

In the case of moderately dense fibreboards the same problem exists, but to a lesser extent, since additional binders are often used in the original manufacture of these grades. The sizing can often be omitted, but any smooth surfaces of this harder board may need to be slightly roughened to give a better grip to the adhesives.

There are also high-density fibreboards, where the smooth side is almost certain to require sanding or sand blasting to secure a firm bond with adhesives.

Some of these veneer-faced fibreboards are being used quite extensively and are sometimes carried in plywood warehouses in standard sizes and thicknesses. It is difficult to compare their qualities with plywood, which is obviously stronger, but these fibreboard combinations are very serviceable in their proper place.

Several of the veneer-fibreboard constructions are shown in Fig. IV. 8. It should be noted that where different density fibreboards

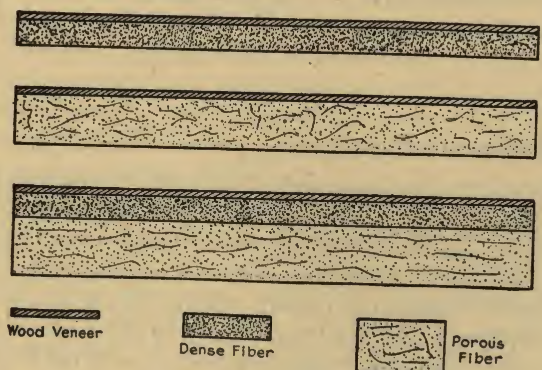


Fig. IV. 8—Veneer and fiberboards plied together.
Upper—where strength and edge molding is required. *Center*—for super insulation where strength is not demanded. *Lower*—for strength and insulation of heat or sound.

are combined with a face veneer, it is necessary first to glue the veneer and the dense fibreboard into a 2-ply, at a higher pressure than in the subsequent gluing operation, when the 2-ply is glued to the porous fibreboard at a lower pressure which will not crush nor diminish the insulating quality of the porous sheet.

Asbestos-veneer Constructions

There are a number of asbestos and veneer combinations that are used largely for fire-resistant requirements. The harder asbestos boards permit excellent bonds with phenolic-resin films. In fact the heat-resistant qualities of the phenolic-resin adhesives are so far superior to any of the other types of glues, that it is practically necessary to use them in any asbestos-veneer combinations.

Asbestos-veneer plywood finds an excellent field of utility in radiator enclosures, coverings for hot-air ducts, and other heat-protective requirements. Since the asbestos sheets are heavy, costly and difficult to fabricate, their utility seldom falls outside of the heat-protective field.

A special type of porous asbestos board has been developed for boat and ship partitions and is fully described under that heading on page 232.

A layer of ⅛-inch asbestos is often incorporated in flush doors, for slow-burning constructions. As one side of this thin asbestos is usually polished, it is important to roughen it by sanding or sand blasting before bonding. It can be used on both solid and hollow flush doors.

The use of a double layer of veneer, not of a decorative character, will often greatly reduce the fragility of asbestos boards for industrial uses.

Plaster and Gypsum Boards

These are usually faced on both sides with a chip board or heavy kraft-paper liner, both to prevent breakage and to protect against surface denting. The bond that can be secured between plaster board and veneer can only be as strong as the facing of the gypsum board. As the moisture content of normal gypsum board often runs up to 15%, difficulties may often be encountered in hot-pressed bonds with any of the resin adhesives. Some method of venting large sheets is desirable, unless the gypsum board can be dried down to such a point as to eliminate the hazard of blisters in hot pressing. Another point to guard in hot pressing is the lack of thickness uniformity in the plaster board, which can be overcome with a cushion of ⅛-inch veneer or a thin rubber blanket.

The facing of gypsum boards with decorative veneer is a project that is in its infancy, but gives promise of providing low cost and attractive interior walls. Veneer facing can also supply a better surface for painting than the normal gypsum boards.

Plywood Metal Sheets

Entirely satisfactory combinations of veneer and some types of sheet metal have been made and are in extensive use in truck bodies, cabs, busses and in streamline trains. Practically all combinations are made to sizes required, since the cutting of such combination sheets presents some difficulties.

The basic problem is to bond firmly together materials with oppositely reacting coefficients of expansion under heat—i.e., metal expands when heated, while wood tends to shrink. Another important problem, but of lesser magnitude, is to join together a porous and a non-porous material, where the adhesive tends to be absorbed on one side only.

Good adhesion cannot be obtained on oily metal surfaces which, therefore, must be pickled and washed clean. A galvanized iron surface produces better adhesion than a raw metal. Surfaces that are too smooth do not bond well with any adhesive, and sanding or sand blasting will be found of great assistance.

Both resins and caseins are used in metal bonding and often an intermediate sheet of cloth is interposed between the metal and the veneer to allow limited "come and go" between the two unlike materials. Latex, or raw rubber, is sometimes combined with the casein to provide limited elasticity, but after a considerable period of time rubber loses its "life," especially at the edges of the plywood, where exposed to the air. Further work is in progress with resins and thin rubber sheets, that give excellent promise of greater durability.

Cloth-faced metal is made under the name "Robertson Bonded Metal," the cloth being attached to the metal with a low-temperature metal, resembling solder, and quickly quenched with water to prevent burning the cloth. Excellent resin bonds can be made to the cloth sides of such metal-cloth sheets, and such combinations are very ductile and can be bent and curved on surprisingly small radii without rupture of the veneer, depending on its thickness and grain direction. This material is finding wide use in elevator cabs and enclosures where the location requires a fireproof metallic partition with a decorative wood face.

Better bonds can be secured on steel than on any other metal, but aluminum can be bonded satisfactorily. Little success has been had in bonding to copper sheets.

Substantial advances in wood and metal bonding are likely to take place in the near future, as present research developments continue.

QUESTIONS

1. In what way does the plywood technique aid in the display of attractive wood figure?

2. How does the design of plywood for strength differ from that intended to express beauty?

3. Compare the construction of normal plywood and laminated wood.

4. What is an all-veneer construction, and why is it used?

5. Describe the general principles of lumber-core construction.

6. Outline several kinds of lumber cores.

7. What is a railed or banded lumber core, and why?

8. Why is a pine block core such an advantage in door construction?

9. Describe the making of a hollow core for a door.

10. What is 2-ply reinforcing and why is it done?

11. Describe the peculiarities of 2-ply cedar-chest construction.

12. Discuss the effectiveness of single-directional pressure in curved dies for plywood.

13. Describe stock panels in some detail, and why they have become established.

14. Tell what "Flexwood" is and how it is applied.

15. In what ways can fibreboards be plied up with veneer?

16. Discuss the problems of making ply-metal.

SECTION FIVE

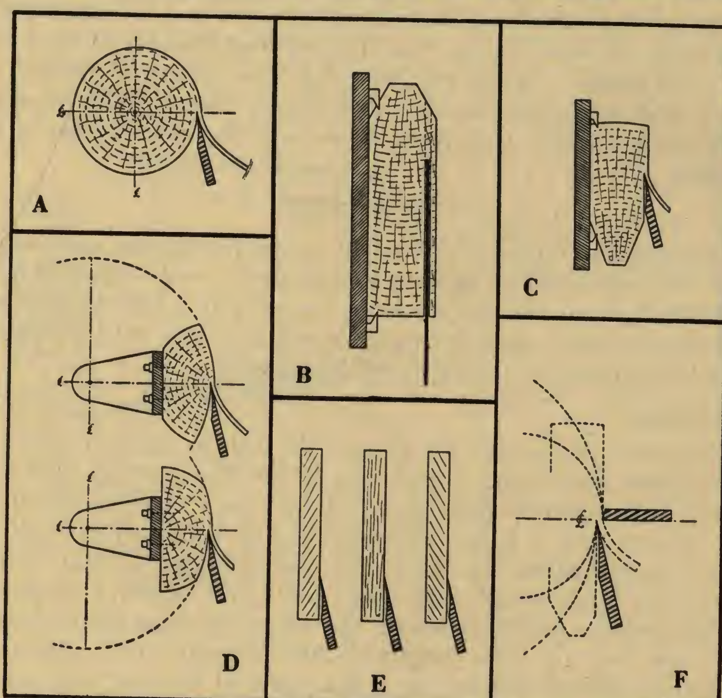
VENEER MANUFACTURING

VENEER PRODUCTION

Veneer-cutting Methods

The mechanical production of veneer does not go back more than 100 years, although thin sheets of wood had been laboriously shaved or sawn for decorative purposes thousands of years ago.

There are four principal methods of veneer cutting, now in use:



Courtesy, Furniture Index

Fig. V. 1—Methods of cutting veneer.

A—rotary cutting on a lathe. *B*—sawn veneer on a segment saw. *C*—veneer produced on a slicer. *D*—half-round veneer on a lathe with stay log. Upper shows back cutting. Lower shows regular half round. *E*—veneer knives may cut differently according to direction of wood grain. *F*—showing relation of pressure bar (above) to knife (below) in rotary, slice and half-round veneer cutting.

Rotary veneer, lathe cut representing upwards of 90% of all veneer production. (Fig. V. 1A)

Sliced veneer, a flat cutting, shearing process for face veneers of value. (Fig. V. 1C)

Half-round veneer, intermediate between rotary and sliced veneers. (Fig. V. 1D)

Sawn veneer, a rip-saw process, originally developed for quarter-sawn oak. (Fig. V. 1B)

In general rotary veneer lathes are used for what is termed commercial veneer, plain cut and mostly unfigured woods, where strength is the predominant requirement. It is a continuous process, more in line with modern tempo. Sliced veneer, on the contrary, is an intermittent process, more precise than rotary, that is utilized for thin-face veneer, where appearance is the most important factor. Rotary cutting is like unwinding a roll of paper and is adaptable for all grades of veneer from the cheapest box shooks to attractive bird's-eye maple. Slicing may be radial (for quartered veneer) or at any other angle that reveals the maximum beauty. With improvements made in slicer technique, the demand for sawn veneer is decreasing.

Rotary Veneer

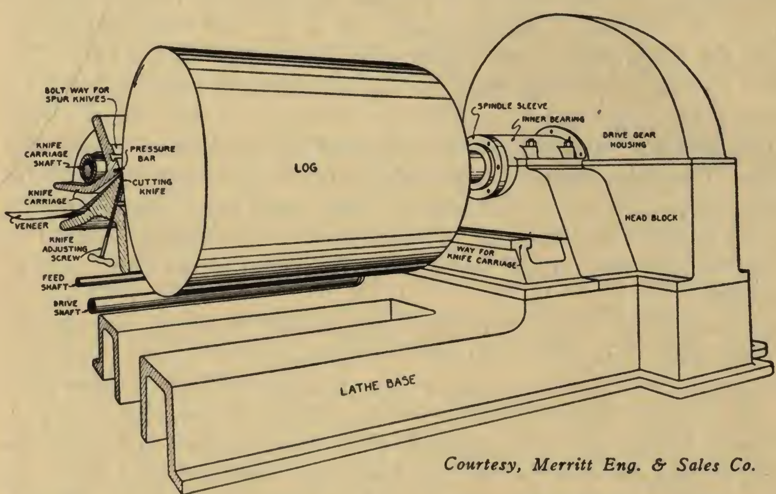
This accounts for over 90% of all veneer production, on a superficial area basis, and its product is used over a wide range of quality products from the cheapest berry boxes up to a few of the finest face veneers, such as curly maple, in which rotary cutting best reveals the artistic characteristics of the growth.

Dimensions

Customary thicknesses are from 1/40 inch to ¼ inch, although both thinner and thicker veneers can be cut from certain species of wood. As a practical matter the bulk of rotary veneer comes from logs up to 8 feet in length, although 10-foot lathes are not uncommon. A few lathes are in service that produce 12- and 16-foot veneer, but long, straight, clear logs are scarce, and the longer the log the greater the diameter of the core that must be discarded. Logs are cut to lathe lengths, with adequate trim allowances (approximately 6 inches), on a drag saw of circular, reciprocating or band-saw types. This cutting to length immediately precedes lathe cutting to prevent end checking, which may be serious in warm climates. These shorter logs, or bolts, are usually cooked in hot water for a matter of hours to bring the wood fibre into the best condition for clean, smooth cutting.

Cooking vs. Steaming

Cooking in reinforced concrete vats is usually preferred to steaming, as this gradual and better controlled process is less likely to damage the wood structure than the more abrupt steam treatment. However, there are many advocates of the steaming method, where free steam is introduced directly into piles of logs or bolts. In general, steaming is more violent than cooking in water, and more adaptable to species that do not rupture under rapid and sudden increase in heat. Still another variant in this preparation process is to cover a pile of logs with its own sawdust, and allow the steam to seep slowly through the pile. This method is slow and principally adaptable to a few high-grade species, such as walnut, where this stewing process tends to darken the lighter color of the sapwood, a distinct sales advantage. Times and temperatures of these preparatory processes vary with the species, size, age (since tree was felled), and the character of the veneer to be cut. Experience has indicated that the harder (more dense) the species and the more difficult to



Courtesy, Merritt Eng. & Sales Co.

Fig. V. 2—Perspective view of standard lathe, with left end removed to show cutting mechanism.

cut, the longer the preparation period, and in general the lower the temperature. Stumps and crotches (for slicing) require very low temperature (100° F.) for several days, as so much of the cutting is across the grain, so that fibres have to be severed rather than separated. Some of the softer woods, if fresh from the stump, can

be cut satisfactorily cold, i.e., without preliminary heating. Among these are poplar, basswood, cottonwood, and certain of the conifers, some of which tend to produce fuzzy veneer when cooked.

Barking

Logs must be barked immediately on removal from the cooking or steaming vats, while hot, except as noted. Most of the barking is done manually with axes and flat chisel-like bars, and the more apparent defects are cut out. Mechanical barkers have been found satisfactory at some plants, although they work best on smooth, straight, round and well-tapered logs, still leaving the task of hand barking for irregular and crooked logs. The time from the vat to the lathe should be as short as possible, while the log is in most favorable condition for cutting.

Standard Lathes

A standard type of lathe is shown in Fig. V. 2, with one end removed to show the cutting mechanism. This cutting mechanism is very similar to that shown in greater detail for a veneer slicer in Fig. V. 5. The log revolves against the knife, and the pressure bar holds the wood firm at the instant of cutting (Fig. V. 1 A, F). The knife carriage is moved into the log by automatic feed screws revolving at a speed that controls the thickness of the veneer. The r.p.m. of these feed screws are adjusted by a series of changeable gears. The lathe centers are provided with dogs having lugs that are pressed into the end of the logs or bolts, most dogs being approximately 6 inches in diameter so that cores can be safely reduced to 7 inches. On short small lathes these dogs may be as small as 3 to 4 inches.

As the veneer comes from the lathe it may be drawn out on the clipper table some 20 to 30 feet, in piles several inches thick, for clipping to such widths as allow for shinkage in drying. However, in the case of logs with defects of consequence, the veneer is customarily broken on each circumference at the defect, and carefully piled so that the defects can be clipped out with the least loss. In less exacting requirements, such as box shooks, the veneer may be drawn from the lathe without regard to defects, and run under an automatic clipper.

The rewinding of rotary veneer, while still wet after cutting and before clipping, has been done successfully both in Europe and Canada. It allows more rapid lathe operation and affords more time for careful inspection at the clipper. It can be used only on clean, high-grade veneer.

Lathe Speeds

Customary lathe speeds are from 30 to 60 r.p.m., and an experienced crew can handle veneer at the delivery rate of 150 to 200 lineal feet per minute.

It is desirable on many lathe operations to have a constant flow of veneer on the delivery table, but there are certain limiting conditions. Economy in time requires that all preliminary cutting, or "round up," be done at as high a speed or as thick a cut as practicable, since it is waste.

The average spindle speed of most production lathes is around 30 to 50 r.p.m., except for face veneer, which often is 20 r.p.m. On an average of 30 r.p.m. the delivery speed will vary from 188 f.p.m. on a 24-inch in diameter log to 63 f.p.m. when the log is reduced to 8 inches in diameter. It is difficult to arrange delivery clipper equipment and to man a crew to work efficiently over such a wide range. Various plans have been devised, none of them wholly satisfactory, to meet this condition. It is further complicated by the fact that 1/20-inch veneer is light and easily handled but more fragile than thicker veneer, while ¼-inch veneer is heavy to handle and must be cut more slowly, due to power demands. The species or character of log also has a bearing on speed; i.e., basswood can be cut faster than hard maple.

Hence the ideal arrangement would be three or four constant delivery speeds—at 100, 125, 150, and possibly 200 f.p.m. The speed requirements of such a program are outlined in Table V. 1. Such an arrangement should have the main drive connected with the feed-screw mechanism so that the operator would have no further concern about speed regulation after once starting the production cut subsequent to the round-up. This could be accomplished mechanically by variable-speed transmissions, although few such installations are yet in operation.

Some veneer mills utilize a series of fixed speeds, such as 24, 30, 36, and 48 r.p.m., and set these speeds (by change gears or belts) for each log, or in the case of large logs, interrupt the operation to change speeds. The result of such a plan is shown in Table V. 2.

Variable-speed motors have been adopted for such a program with fair success, but many types of motors will race unless under approximately full load, which is objectionable when entering or leaving a cut. The variation in power demand between 1/20-inch and ¼-inch thicknesses also causes racing and is a handicap to a variable-speed motor. Frequency changers are preferable, giving greater flexibility and more constant speeds under varying loads.

Table V. 1
Lathe-spindle Revolutions (per Minute) for Constant Delivery Speed

Log Diameter, Inches	Constant Delivery Speed, Feet Per Minute: 100	125	150	200
7	54.5	*	*	*
8	47.7	59.8	....	....
9	42.5	52.7	....	....
10	38.2	47.8	57.2	....
11	34.7	43.4	52.1	....
12	31.8	39.8	47.7	....
13	29.4	36.7	44.1	58.8
14	27.3	34.1	40.9	54.5
15	25.4	31.8	38.2	51.0
16	23.8	29.8	35.8	47.7
17	22.5	28.1	33.7	45.0
18	21.2	26.5	31.8	42.5
19	20.1	25.1	30.1	40.2
20	19.1	23.9	28.6	38.2
21	18.2	22.7	27.3	36.4
22	17.3	21.7	26.0	34.7
23	16.6	20.8	24.9	33.2
24	15.9	19.9	23.9	31.9
27	14.2	17.7	21.3	28.4
30	12.8	15.9	19.2	25.5
33	11.6	14.5	17.4	23.2
36	10.6	13.2	15.9	21.2

* Over 60 r.p.m. considered impractical. Under 20 r.p.m. probably unnecessary.

These tables (V. 1 and 2) apply principally to the cutting of hardwood veneers for the better grades of plywood. When veneer is cut for box shooks, speeds may be considerably higher, since no attempt is made to cut out defects or to select veneer for soundness or figure. The veneer for baskets and fruit and vegetable containers is also cut at high speeds, and usually in connection with an automatic clipper, coupled in tandem with the lathe.

The log diameters indicated will cover the more usual ranges of the hardwoods. The computations can be extended, if required, for such larger sizes as are customary on the Pacific Coast.

Table V. 2
Actual Lathe Delivery Speeds, on 48, 36, 30 and 24 R.P.M. within 10% of Standards

Standard Delivery Speed	*Diameter of Log, In.*	*Spindle R.P.M.*	*Feet per Minute*
100	8	48	100.5
	10	36	94.2
	12	30	94.2
	14	30	110.0
	16	24	100.5
	18	24	113.1
125	10	48	125.7
	12	36	113.1
	14	36	131.9
	16	30	125.7
	18	24	113.1
	20	24	125.7
	22	24	138.2
150	12	48	150.8
	14	36	131 9
	16	36	150.8
	18	30	141 4
	20	30	157.1
	22	24	138.2
	24	24	150.8
	26	24	163.4
175	14	48	175.9
	16	36	150.8
	18	36	169.6
	20	36	188.5
	22	30	172.8
	24	30	188.5
	26	24	163.4
	28	24	175.9
	30	24	188.5
200	16	48	201.1
	18	48	226.2
	20	36	188.5
	22	36	207.3
	24	30	188.5
	26	30	204.2
	28	30	219.9
	30	24	188.5
	32	24	201.1
	34	24	213.6
	36	24	226.2

Loose and Tight Cutting

It is to be noted that thicker rotary-cut veneer will tend to be stretched on the concave, or under, side when flattened out, and to develop cracks and checks, as shown in Fig. V. 3. The convex, or

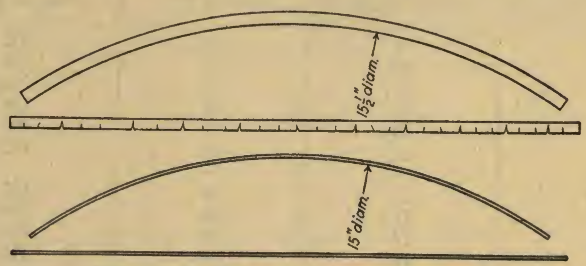


Fig. V. 3—Tight- and loose-cut veneer.
Above—cutting checks developed in thick (⅛- to ¼-inch) veneer. *Below*—absence of cutting checks in 1/28-inch veneer, can be used both sides.

outer, side of rotary veneer under compression is called the **tight side**, while the inner side, under tension, is called the **loose side**. Careful adjustment of the pressure bar and sharp knives will reduce this checking. Veneer is also called **loose cut** when the wood fibre is intentionally ruptured on the inner or concave side, so that ultimate curling or warping of plywood is reduced, since **tight-cut** veneer tends to reassume its original curved shape.

Factory Layout

Factory size and shape, as well as columns and windows, impose limitations on the arrangement of a veneer department, but a typical

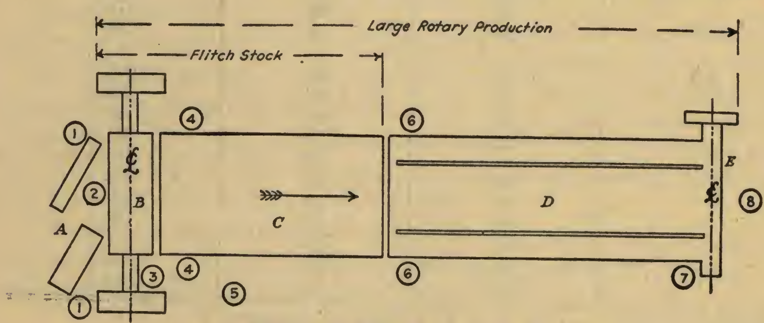


Fig. V. 4—Standard lathe layout and crew.
A—log deck at floor level; *B*—rotary lathe; *C*—delivery table, sloping up to clipper chain; *D*—conveyor chain to clipper; *E*—clipper for trimming veneer. The standard crew, totaling 11 workmen, is as follows: (1) 2 log peelers, varies with lathes in service; (2) 1 log hanger; (3) 1 lathe operator and crew foreman; (4) 2 off bearers or breakers; (5) 1 waste collector; (6) 2 off bearers, for large production; (7) 1 clipper operator; (8) 1 clipper off bearer.

and advantageous layout is given in Fig. V. 4. If the lathe is used wholly for half-round veneer cutting, the clipper table and its crew may be eliminated as indicated.

Sliced Veneer

Purpose of Slicing

This process of veneer cutting is used especially for face veneers where the angle of cut, with regard to veneer grain, may be varied to reveal the most attractive figure, which can be matched to give consistent or contrasting effects in the plywood. While it can be, and often is, used on any species, it is more often limited to such species as mahogany, walnut and other distinctly face woods of value, many of which are imported.

Sliced veneer has the distinct advantage of being cut flat, without tendency to curl back in drying to a previous curvature, as was noted in the cutting of rotary veneer on page 104. There is practically no rupture of the fibre, as the slight bending of the wet veneer, as it leaves the knife, produces no permanent distortion. This is particularly useful in face veneers where adjacent sheets are of such similar (and often unsymmetrical) figure that turning the neighboring sheets results in a pleasing and balanced figure.

Flitches and Their Preparation

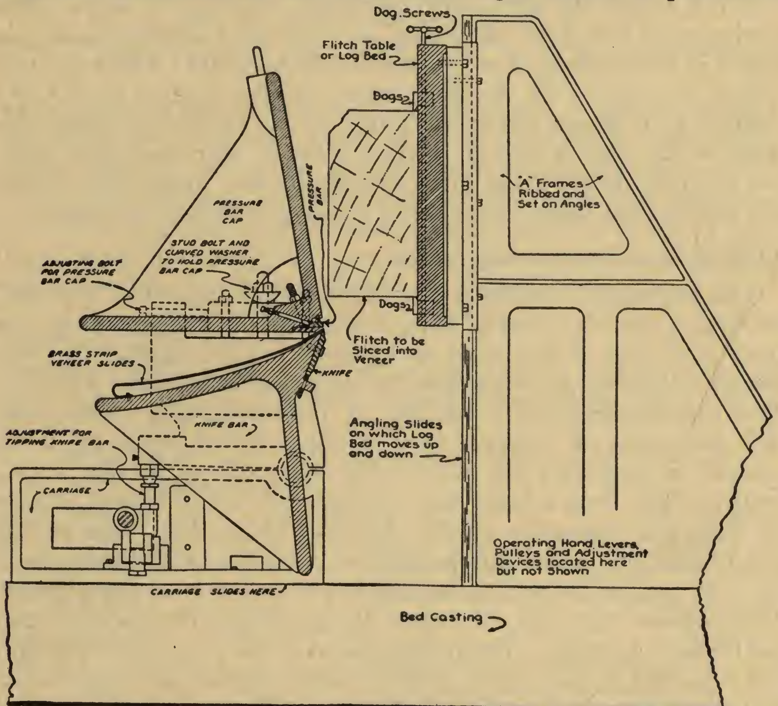
The preparatory treatment for slicing differs from that for rotary cutting in that the original logs of full lengths are opened up on a large band mill to determine the character of the figure. This will permit a decision as to whether the most desirable veneer will come from radial segments of the log, or from rectangular pieces that will give plain-cut veneers. If it is found that a radial cut is advisable, the segments are sawn to the shape shown in Fig. V. 1C, usually eight from a large log, although there may be any number of segments, depending on the character of the log. This process has carried the name **quartering** for many years, probably from the early practice of quartering logs to produce quarter-sawn lumber. It is obvious that only the center board or sheet of veneer is truly quartered, i.e., radial. The outside angle of each segment is usually sawn parallel to the radial center of each segment for convenience in mounting on the log bed of the slicer. These segments or other shapes that may occur in opening and trimming crotches or stumps for veneer cutting are called **flitches**, and the resulting veneer is called a **flitch of veneer.**

Most of the bark is sawn off in the preparation of flitches for slicing, but what remains is removed manually after cooking or

steaming. This tenderizing or mellowing of flitches is even more essential in slicing than in rotary cutting, due to the large amount of fancy figure cut across the grain. The comments on the preparation of rotary logs or bolts (page 99) apply equally well to slicer flitches. The **backboard** or base of the flitches, used to clamp to the log bed with screw dogs, is usually less than 1 inch thick, and is frequently sold as thin lumber for drawer sides and backs.

Dimensions

The usual thickness of face veneer is 1/28 inch, although on such large areas as doors and office desk tops it may be from 1/12 to ⅛ inch. Slicers are usually made to cut flitches from 12 to 16 feet long, and sometimes 18 feet long, affording a source of production



Courtesy, Johnson City Foundry & Machine Co.

Fig. V. 5—Cross-section diagram of a standard veneer slicer.

for longer veneers than most rotary lathes. The more precise character of slicer work permits the production of veneer as thin as 1/100 inch, but ⅛ inch is about the limit of thickness.

Vertical Slicers

Veneer slicers usually cut their product in a vertical plane, although a few are made to operate horizontally. A vertical slicer is shown in cross-section in Fig. V. 5, with important parts captioned. The cutting mechanism, shown on the left side of the illustration, is essentially the same as a rotary-veneer lathe, and is automatically moved into the wood (flitch) by the two feed screws, which, however, in this case are actuated by a rachet. The **log bed**, with flitch clamped to it, reciprocates up and down on angling slides, as shown at the right of the illustration, the top portion being toward the reader, and angling down and away from that position. This gives a shear cut that insures smoother cutting on highly figured flitches, where "endy" wood predominates. While regular straight-grained logs, as a rule, are mounted horizontally on the log bed, this position may be made angular to produce a less fuzzy cutting, resulting in a type of double shear.

Sampling and Marking

The product of the slicer is removed by two off-bearers and each sheet turned over as it is laid on the pile, so that the last surface cut is always on the top of the pile, as is shown for half-round cutting in Fig. V. 9. This leaves all sheets of veneer in sequence, exactly as cut, and this order is meticulously preserved through the drying operation. Each flitch is then sampled by a typical sheet from near the top, center and bottom of the flitch. The samples are hinged with tape, for convenient packing in a trunk, and used by the salesman in his displays and negotiations. Samples are marked as follows:

(Flitch number)	36,752 A
(Sample)	1 of 3
(Scale, square feet)	745

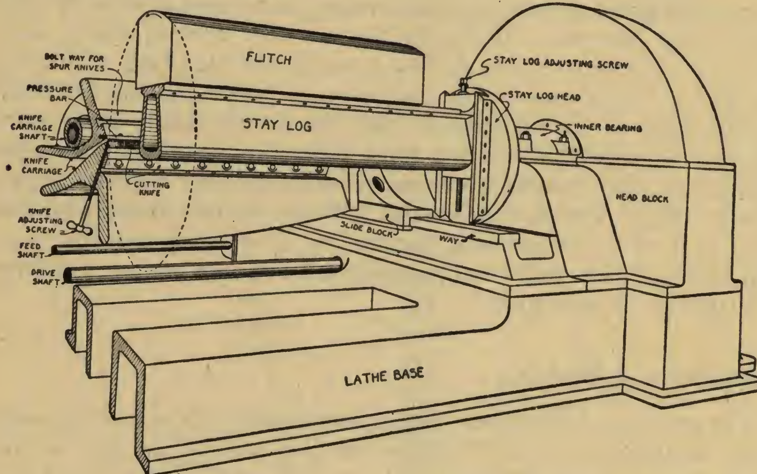
Different flitches from the same log are marked A, B, C, D, etc. The area of ·ach flitch is called the **scale**, and marked in the bottom line above. The top sample is numbered 1, the center 2, and the bottom 3. In exceptional cases there may be more or less samples, and this is indicated in the same way.

Half-round Veneer

This is an intermediate knife-cutting process, a compromise between the rotary lathe and the slicer, as can be noted in Fig. V. 1D.

Stay Log

The standard rotary lathe is provided with a **stay log**, mounted at the ends in eccentric chucks, so that the cut is made on a relatively long radius, as shown in Fig. V. 6. The stay log face is



Courtesy, Merritt Eng. & Sales Co.
Fig. V. 6—Standard veneer lathe with stay log attachment.

provided with a series of holes so that the flitch can be bored with shallow holes and bolted firmly to the stay log. The eccentricity of the stay log does not often exceed 12 inches, due to the requirements of rigidity in intermittent cutting.

There are two types of half-round cutting, **regular,** where the heart of the log is toward the stay log, and **back cut,** where the heart of the log is away from the stay log. While the stay log affords an opportunity to obtain a more desirable figure in certain types of flitches, and a slight increase in width of veneer over slicing, yet half-round and sliced veneer are usually considered reasonably equivalent in character. It frequently happens that a veneer lathe is more available than a slicer, and more easily operated on short flitches. Some veneer manufacturers mount logs eccentrically on regular chucks (without stay log attachment) and thus secure an almost half-round cut, but this will not produce back cutting. Such veneer is not regarded as the equal of the standard half-round product. This is done most frequently on stumps which can be described as the enlarged butt ends from the first log in the tree.

Preparation and Sampling

The preparation of flitches, both as to opening logs for determining the desirable location of flitch cuts, as well as to the cooking and steaming, is the same as previously described for rotary cutting and slicing. The opening of a small log and the mounting of the resulting flitches on a stay log are shown in Fig. V. 7. The detailed

Fig. V. 7—Detail of mounting flitches for half-round cutting. *A*—back cutting. *B*—regular half round.

construction of a standard veneer lathe, with stay log attachment, is shown in Fig. V. 6, where the cutting mechanism is exactly the same as in the lathe operation for rotary veneer, and the differences are only those of the method of mounting the flitch on the stay log rather than between the lathe chucks.

The sheets of half-round veneer are kept in sequence, sampled, marked and sold as described for sliced veneer on page 107.

Courtesy, Wood Mosaic Co.

Fig. V. 8—Method of mounting stump flitches on stay log.

A photographic view of a half stump, just mounted on a stay log, ready to cut, is shown in Fig. V. 8. The other half of the stump is shown in the right foreground, bored and ready to attach to the same stay log. Sometimes both units can be mounted on the same stay log, end to end, and cut half-round at the same time, but often they are cut singly.

The other side of this same lathe, with a gradually accumulating pile of flitch veneer in the foreground, is shown in Fig. V. 9. The

Courtesy, Wood Mosaic Co.

Fig. V. 9—Cutting half-round, black walnut, stump veneer.

flitch is a long walnut stump, or butt, as can be identified by the light-colored sapwood at the edges. The next flitch, ready to be mounted, can be seen, hung from a chain block, directly in rear of the lathe operator.

Sawn Veneer

This method of veneer production accounts for a relatively small amount of the veneer used. As in the case of slicing, it is cut flat and is wholly free of cutting checks, as can be noted in Fig. V. 1B.

Preparation of Logs

Since this is the only veneer-cutting method that uses a saw, in contrast to a knife in the lathe and the slicer, it does not require preliminary cooking, steaming or barking. Flitches are made on the band mill and several methods of opening a log and sawing it into flitches are shown in Fig. V. 10.

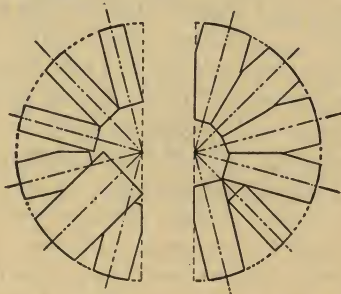


Fig. V. 10—Methods of flitching a log for the segment saw.

An actual photograph of the operation of flitching a log for quarter sawing, on a band mill, is shown in Fig. V. 11. The method of

Courtesy, Wood Mosaic Co.

Fig. V. 11—Flitching a white oak log on a band mill.

flitching thus shown is slightly different from either of those indicated in Fig. V. 10.

Segment Saw

The saw used for veneer production is termed a **segment saw**, since it consists of a sturdy heavy hub, to the tapering flanges of which relatively narrow and shallow-toothed saw segments are bolted, as shown in Fig. V. 12. A large, solid circular saw, such as used for lumber production, produces far too much saw kerf, 3/16 to ¼ inch, and would be too wasteful of veneer material. A properly conditioned segment saw will operate on 1/20- to 1/16-inch saw kerf, which means that in cutting 1/20-inch oak veneer, approximately half of the flitch is lost. This has always been one of the serious obstacles in the cost of sawn veneer. Most sawn veneer is quarter cut, although plain cut is desired for some purposes. Formerly nearly all quarter-sawn oak veneer was so made, as it was then considered that the conspicuous flake figure of oak could only be preserved by sawing, i.e., any knife cutting would shatter this flake, which is the attractive characteristic of oak for office furniture. This flake is produced by the cells or food pockets of the oak tree, which grow in a radial direction, at right angles to the normal wood cells, which are vertical. Consequently, in drying, which shrinks the wood widthwise of the cells, it is likely that checks will develop where the vertical cells shrink in a horizontal direction, and the horizontal

Courtesy, I. T. Williams & Sons Co.

Fig. V. 12—Battery of four segment saws, set on an angle for stay log clearance.

cells in a vertical direction, causing a line of cleavage between. Hence the pull and strain of knife cutting may tend to produce stresses at this point, and start an incipient cleavage. With the improvement of slicer technique, this difficulty has been largely overcome. Neither sliced nor rotary veneer has a saw-kerf waste, and both give better yields than sawn, so that the knife-cut veneer is usually more economical than sawn veneer. Other uses for sawn veneer are flush and panel doors, where the grain of sawn veneer matches the interior trim of lumber better than does rotary-cut veneer. Piano manufacturers prefer sawn veneer for grand rims and pin planks, as it is firmer and more solid cut than either rotary or sliced. Forms for drying woolen goods, without shrinkage, and venetian-blind slats are better made from sawn than knife-cut veneer. Spanish cedar veneer for better-grade cigar boxes is often sawn veneer.

Dimensions

Segment saws are equipped with reciprocating log beds or stay logs to which flitches are clamped with dogs. These stay logs move horizontally into the saw, which revolves into the wood. Lengths of flitches normally run up to 16 feet, and the ways on which the stay logs move can be extended considerably further if desired.

Thicknesses of sawn veneer range from 1/20 to ⅜ inch, and can be made even thicker. A properly filed and set segment saw will show very few tool marks, and those that are found are shallow enough to sand out. Sawn veneer is kept in flitches, but is sold by area and not by samples. Adjacent sheets may be turned to make **herringbone** oak figure, but such veneer is known as **bastard** sawn, and ranges between 10° and 30° away from a true quarter, or radial line.

Veneer Drying

It is important that the moisture content of veneer be reduced to approximately 10% as soon as possible after cutting, and this is even more essential in veneer that has been cooked and has a strong tendency to develop mold and fungus. Some species lose their deep, strong color characteristics when drying is not properly timed.

Types of Veneer Driers

Veneer driers, in general, are long chambers, equipped with rollers or belts to advance the veneer longitudinally through the chamber. Fans and heating coils are located along the sides of the chambers, circulating and recirculating the air back and forth across the cham-

ber. From an ideal drying standpoint, the veneer should move in one direction only, permitting the proper amount of moisture deficit, or drying power, progressively along the length of the chamber, so that a low temperature and high humidity can be maintained at the start of the drying process, which air condition can be gradually changed to a high temperature and low humidity at the end. From a practical standpoint this ideal method only uses one side of the rolls or belts and greatly reduces ultimate capacity. Consequently, most driers are now made two-way, as shown in Fig. V. 13. Thus, green veneer is fed in and also discharged at both ends. The internal air conditions in these driers depart from the ideal described above in that the interior of the entire drier is maintained at approximately the same degree of temperature and humidity, usually automatically controlled.

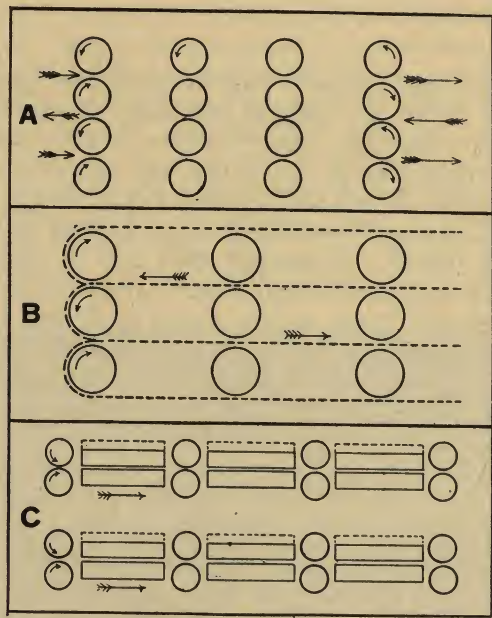


Fig. V. 13—Diagrams of types of veneer driers.
A—roller drier, two-way. *B*—mesh belt drier, two-way. *C*—progressive plate drier, one-way.

Three types of drier mechanisms are shown in Fig. V. 13. The upper, A, is a roller drier in which the veneer is slightly pinched between the rollers by the weight of the upper roller. This type is made up to six decks of rollers, handling five layers of veneer simultaneously. All rollers are driven. The center type, B, has shafts

spaced further apart, driven at each end of the chamber, but all shafts equipped with a series of sprocket wheels that move endless belts of a wire-mesh type so that air circulates fully around both sides of the veneer, as shown in Fig. V. 14. These belts are not

Courtesy, Proctor & Schwartz, Inc., & Underwood Veneer Co.

Fig. V. 14—Endless belt veneer drier. Veneers are held between open wire mesh belts.

quite so effective in keeping the veneer flat as are the rollers in A, but they are sometimes safer for fragile veneer that breaks easily under pressure. The third type, C, has a series of alternate pairs of rollers and heated platens, operating intermittently. When the platens are open the veneer is forwarded by the rollers, but only the distance of one platen. The rollers stop, the platens close for a short interval; the platens open, the rollers advance the veneer again, and so on. This makes for flat veneer, but lacks the productive capacity of the continuous machines above.

Some particularly choice veneers are still air dried, either in racks or lofts, a time-consuming operation that largely has passed out of use.

Since woods of various textures dry more rapidly through severed end cells than through the surface or edges of veneer sheets, drying is likely to cause the ends of the veneer sheets to wrinkle more or less, and sometimes to split. Drying more slowly, or at lower temperatures will reduce this wrinkling. The preponderance of endy wood in highly figured veneer, such as crotches and stumps,

causes more than normal wrinkling, which requires special treatment before such veneer can be used in plywood assemblies. Endy veneer may be described as that in which many wood cells are severed at an angle on the surface of the veneer. An observer thus tends to look into the open cells of the wood, the stains and fillers find more to do on such open ends, and the general appearance is of a darker shade than the veneer that is cut approximately parallel to the wood cells, where few are severed.

Drying Speed

The drier adjustment for different thicknesses of veneer is one of total time required to pass through the length of the drying chamber. As an example for a given length of drier, the drying cycle for 1/28-inch veneer might be 12 minutes, while that for ⅛-inch veneer would be closer to 30 minutes. Such driers are seldom less than 50 feet long, frequently up to 100 or 120 feet in length. The longer the drier the better the quality of the drying, except that for very thin stock the shorter chambers may be satisfactory. Temperatures up to 225°F. are customary, although for thick veneers of species that tend to caseharden, such as maple, lower temperatures and longer times are advisable.

Shipping Dry

Most veneer is dried down to 10% moisture content (for moisture-content formula, see page 299) at point of production, since this is about the normal condition that will not absorb or give off much moisture in handling, storage or shipping. It is dry enough to eliminate the hazard of mildew and other discoloration, but still damp enough to be limber and to handle without undue breakage.

After drying, veneer may be crated. In fact, most flitch veneer is crated promptly flitch by flitch, to avoid confusion in preserving sequences. Plainer veneers may be bundled or bulked down to mellow, preparatory to shipment.

LOG MEASUREMENT

Many methods and rules have been devised to represent the anticipated lumber yield in board feet (12 by 12 by 1 inch) from logs of various shapes and sizes. Most of these were local in character, and have ceased to be important, but those that follow here have been widely recognized and used.

The problem of predetermining the probable yield, using the diameter of the small end as a base, is complicated by various degrees

of taper, differing log lengths, shrinkage in drying, and the inevitable waste of saw kerf, and wany edges.

Since logs chosen for veneer cutting are a relatively small proportion of the whole, selected from saw logs, the same log scales are applied to both. It is quite apparent that the yield factor from veneer is entirely different from that for lumber. However, the industries involved have tolerated this crude method of measurement, rather than develop an acceptable and more accurate basis. In the main the log rules and scales strongly favor the buyer, since the arguments of the man with the money are likely to prevail over those of the man who wants to get the money.

These log scales apply to timber cut in the United States and Canada. In the case of imported logs there is considerable difference in practice, and no general method can be cited. Mahogany logs from Africa are usually hewn square, and since these are usually sliced, the waste is a combination of saw kerf and backboards, the irregularly thick pieces required for clamping on the stay log. Other species may be calculated by weight, as well as by estimated cubic content. Traditional and long-established practices are likely to prevail.

The rules by which the more important log scales were determined are outlined, and a condensed tabulation of these scales is given in Tables V. 3—V. 6. There is also a comparison (Table V. 7) of these scales, based on a standard 16-foot length.

Log Scales

Scribner Rule

This is the oldest log scale now in general use. It was originally published in *Scribner's Lumber and Log Book,* although later editions substituted the Doyle rule.

The rule was based on computations from diagrams drawn to show the cross-sectional area of inch boards that can be sawed from logs of different sizes after allowing for waste. The contents of these boards were then calculated and the table thus built up. (See Table V. 3.)

It is generally recognized that this rule is reasonably fair for lumber sawed from small logs, but that for diameters 28 inches and larger, the results are low.

Sometimes the Scribner scale is converted into what is known as the Scribner Decimal Scale, by dropping the units and rounding the values to the nearest tens. This decimal rule is practically the same as the Hyslop Rule.

Doyle Rule

The Doyle rule is variously known as the Connecticut River, St. Croix, Thurber, Moore & Beeman and Scribner rule, this last due to the fact that it is now printed in *Scribner's Lumber and Log Book*. It is employed more widely throughout the entire world than any other log rule.

It is constructed by deducting 4 inches from the small diameter of the log as an allowance for slab, squaring one quarter of the remainder, and multiplying the result by the length of the log in feet. (See Table V. 4.)

The saw mill overrun on this scale is about 25% on small short logs, and even more for long logs of small diameter.

Doyle-Scribner Rule

This combination of Doyle and Scribner rules is largely used for hardwoods, and is the official rule of the National Hardwood Lumber Association of the United States.

By this combined rule, the contents of all logs 27 inches and under are measured by the Doyle rule, and the Scribner rule is used to measure logs 28 inches and over in diameter. (See Table V. 4.)

Spaulding Rule

This is the statute rule of California, since its adoption by the legislature in 1878. It is also used widely in Oregon, Washington, Utah and Nevada. The results are very similar to those of the Scribner rule.

It was originally computed from carefully drawn diagrams of logs from 10 to 96 inches in diameter at the small end. (See Table V. 5.)

British Columbia Rule

This is authorized by the government of British Columbia.

It is computed by deducting 1½ inches from the mean diameter in inches at the small end on the log; square the result and multiply by .7854 to find the area; deduct three elevenths; divide by 12 to bring to board measure and multiply by the length of the log in feet. (See Table V. 6.)

Certain adjustments are made for logs longer than 40 feet.

Table V. 3
Scribner Log Scale in Board Feet

(Based on diameter at small end of log)

Diameter (*Inches*)	*Length of Log in Feet*							
	10	12	14	16	18	20	22	24
12	49	59	69	79	88	98	108	118
13	61	73	85	97	109	122	134	146
14	72	86	100	114	129	143	157	172
15	89	107	125	142	160	178	196	214
16	99	119	139	159	178	198	218	238
17	116	139	162	185	208	232	255	278
18	133	160	187	213	240	267	294	320
19	150	180	210	240	270	300	330	360
20	175	210	245	280	315	350	385	420
21	190	228	266	304	342	380	418	456
22	209	251	292	334	376	418	460	502
23	235	283	330	377	424	470	517	564
24	252	303	353	404	454	505	555	606
25	287	344	401	459	516	573	630	688
26	313	375	439	500	562	625	687	750
27	342	411	479	548	616	684	752	821
28	363	436	509	582	654	728	801	874
29	381	457	533	609	685	761	837	913
30	411	493	575	657	739	821	903	985
31	444	532	622	710	799	888	977	1066
32	460	552	644	736	828	920	1012	1104
33	490	588	686	784	882	980	1078	1176
34	500	600	700	800	900	1000	1100	1200
35	547	657	766	876	985	1095	1204	1314
36	577	692	807	923	1038	1152	1267	1382
37	644	772	901	1029	1158	1287	1416	1544
38	669	801	934	1068	1201	1335	1468	1602
39	700	840	980	1120	1260	1400	1540	1680
40	752	903	1053	1204	1354	1505	1655	1806
41	790	954	1113	1272	1431	1590	1749	1908
42	840	1007	1175	1343	1511	1679	1847	2015
43	870	1046	1222	1396	1571	1745	1919	2094
44	930	1110	1295	1480	1665	1850	2035	2220
45	950	1139	1329	1518	1707	1898	2088	2278
46	990	1190	1388	1587	1785	1983	2181	2380
47	1040	1242	1449	1656	1862	2070	2277	2484
48	1080	1296	1512	1728	1944	2160	2376	2592
50	1170	1400	1640	1870	......	2340	2574	2808
52	1270	1520	1770	2020	......	2530	2783	3036
54	1370	1640	1910	2180	......	2730	3003	3276
56	1470	1760	2060	2350	......	2938	3232	3526
58	1580	1890	2210	2520	......	3154	3469	3785
60	1690	2030	2370	2700	......	3380	3718	4056

DOYLE—SCRIBNER

Scribner Decimal Rule, below and left of broken line.

Table V. 4
Doyle Log Scale in Board Feet
(Based on diameter at small end of log)

	Diameter (Inches)	*Length of Log in Feet*							
		10	12	14	16	18	20	22	24
DOYLE—SCRIBNER	6	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0
	7	5.6	6.8	7.9	9.0	10.1	11.3	12.4	13.5
	8	10	12	14	16	18	20	22	24
	9	16	19	22	25	28	31	34	37
	10	23	27	32	36	41	46	50	54
	11	31	37	43	49	55	61	67	74
	12	40	48	56	64	72	80	88	96
	13	50	61	71	81	91	101	111	122
	14	62	75	88	100	112	125	137	150
	15	75	91	106	121	136	151	166	181
	16	90	108	126	144	162	180	198	216
	17	106	127	148	169	190	211	232	253
	18	122	147	171	196	220	245	269	294
	19	141	169	197	225	253	280	309	338
	20	160	192	224	256	288	320	352	384
	21	181	217	253	289	325	361	397	433
	22	202	243	283	324	364	404	445	486
	23	226	271	313	359	406	452	496	541
	24	250	300	350	400	450	500	550	600
	25	276	331	386	441	496	551	606	661
	26	302	363	423	484	544	605	665	726
	27	330	397	463	530	596	661	726	794
	28	360	432	504	576	648	720	792	864
	29	391	469	547	625	703	782	860	938
	30	422	507	591	676	761	845	930	1014
	31	456	547	638	729	820	912	1004	1094
	32	490	588	686	784	882	980	1078	1176
	33	526	631	736	841	946	1051	1156	1262
	34	562	675	787	900	1012	1125	1237	1350
	35	601	721	841	961	1081	1202	1322	1442
	36	640	768	896	1024	1152	1280	1408	1536
	37	681	817	953	1089	1225	1361	1497	1634
	38	723	867	1011	1156	1300	1446	1590	1734
	39	765	910	1070	1225	1379	1530	1684	1838
	40	810	972	1134	1296	1458	1620	1782	1944
	41	856	1027	1198	1369	1540	1711	1882	2052
	42	902	1083	1264	1444	1625	1805	1986	2166
	43	951	1141	1331	1521	1711	1902	2091	2282
	44	1000	1200	1400	1600	1800	2000	2200	2400

Table V. 5
Spaulding Log Scale in Board Feet
(Based on diameter at small end of log)

Diameter (Inches)	Length of Log in Feet						
	12	14	16	18	20	22	24
12	58	67	77	87	96	106	116
13	71	82	94	106	118	130	142
14	86	100	114	129	143	157	172
15	103	120	137	154	171	188	206
16	121	141	161	181	201	221	242
17	141	164	188	211	235	258	282
18	162	189	216	243	270	297	324
19	184	214	245	276	306	337	368
20	207	241	276	310	345	379	414
21	231	269	308	346	385	423	462
22	256	298	341	384	426	469	512
23	282	329	376	423	470	517	564
24	309	360	412	463	515	566	618
25			449	505	561	617	674
26			488	549	610	671	732
27			528	594	660	726	792
28			569	640	711	782	854
29			612	688	765	841	918
30			656	738	820	902	984
31			701	789	876	964	1052
32			748	841	935	1028	1122
33			796	895	995	1094	1194
34			845	951	1056	1162	1268
35			897	1009	1121	1233	1346
36			950	1069	1188	1307	1426
37			1006	1132	1258	1384	1510
38			1064	1197	1330	1463	1596
39			1124	1264	1405	1545	1686
40			1185	1333	1481	1629	1778
41	NOT	INCLUDED	1248	1404	1560	1716	1872
42			1312	1476	1640	1804	1968
43			1377	1549	1721	1843	2066
44			1448	1629	1810	1991	2172
45			1512	1701	1890	2079	2268
46			1581	1779	1976	2174	2372
47			1652	1858	2065	2271	2478
48			1724	1939	2155	2370	2586
50			1872	2106	2340	2574	2808
52			2025	2278	2531	2784	3038
54			2184	2457	2730	3003	3276
56			2350	2644	2938	3232	3526
58			2524	2839	3155	3470	3786
60			2704	3042	3380	3718	4056

Table V. 6
British Columbia Log Scale in Board Feet

(Based on diameter at small end of log)

Diameter (Inches)	Length of Log in Feet							
	10	12	14	16	18	20	22	24
12	52	63	73	84	94	105	115	126
13	63	76	88	101	113	126	138	151
14	74	89	104	119	134	149	164	178
15	87	104	121	139	156	174	191	208
16	100	120	140	160	180	200	220	240
17	114	137	160	183	206	229	252	274
18	130	156	181	207	233	259	285	311
19	146	175	204	233	262	292	321	350
20	163	195	228	261	293	326	358	391
21	181	217	253	290	326	362	398	434
22	200	240	280	320	360	400	440	480
23	220	264	308	352	396	440	484	528
24	241	289	337	386	434	482	530	578
25	263	315	368	421	473	526	578	631
26	286	343	400	457	514	571	629	686
27	310	371	433	495	557	619	681	743
28	334	401	468	535	602	669	735	802
29	360	432	504	576	648	720	792	864
30	387	464	541	619	696	773	851	928
31	414	497	580	663	746	828	911	994
32	443	531	620	708	797	886	974	1063
33	472	567	661	756	850	945	1039	1134
34	503	603	704	804	905	1005	1106	1207
35	534	641	748	855	962	1068	1175	1282
36	567	680	793	906	1020	1133	1246	1360
37	600	720	840	960	1080	1200	1320	1440
38	634	761	888	1015	1141	1268	1395	1522
39	669	803	937	1071	1205	1340	1473	1606
40	706	847	988	1129	1270	1411	1552	1693
41	743	891	1040	1188	1337	1485	1634	1782
42	781	937	1094	1249	1405	1562	1718	1874
43	820	984	1148	1312	1476	1640	1804	1967
44	860	1031	1203	1375	1547	1719	1891	2063
45	901	1081	1261	1441	1621	1801	1982	2162
46	943	1131	1320	1508	1697	1885	2072	2262
47	985	1183	1380	1577	1774	1971	2168	2365
48	1029	1235	1441	1647	1853	2058	2264	2470
50	1120	1344	1568	1791	2015	2239	2463	2687
52	1214	1457	1699	1942	2185	2428	2671	2913
54	1312	1574	1837	2099	2362	2624	2886	3149
56	1414	1697	1979	2262	2545	2828	3110	3393
58	1520	1823	2127	2431	2735	3039	3343	3647
60	1629	1955	2281	2606	2932	3258	3584	3910

Table V. 7
Comparison of Log Scales, 16-Foot Lengths, in Board Feet

Cylindrical content = $1/4\pi D^2 \times (16/12) = 1/3\pi D^2$ board feet.

Diam., Small End., inches	*Doyle Scale*	*Scribner Scale*	*Doyle-Scribner Scale*	*Scribner Decimal Scale*	*Spaulding Scale*	*British Columbia*	*Cylindrical Content*
6	4	18	4	20	....	....	37.699
7	9	28	9	30	....	....	51.313
8	16	32	16	30	....	....	67.021
9	25	40	25	40	....	....	84.823
10	36	50	36	60	50	....	104.720
11	49	65	49	70	63	69	126.711
12	64	79	64	80	77	84	150.796
13	81	97	81	100	94	101	176.976
14	100	114	100	110	114	119	205.250
15	121	142	121	140	137	139	235.620
16	144	159	144	160	161	160	268.083
17	169	185	169	180	188	183	302.640
18	196	213	196	210	216	207	339.292
19	225	240	225	240	245	233	378.038
20	256	280	256	280	276	261	418.879
21	289	304	289	300	308	290	461.814
22	324	334	324	330	341	320	506.844
23	359	377	359	380	376	352	553.968
24	400	404	400	400	412	386	603.186
25	441	459	441	460	449	421	654.499
26	484	500	484	500	488	457	707.906
27	530	549	530	550	528	495	763.407
28	576	582	582	580	569	535	821.003
29	625	609	609	610	612	576	880.693
30	676	657	657	660	656	619	942.478
31	729	710	710	710	701	663	1006.36
32	784	736	736	740	748	708	1072.33
33	841	784	784	780	796	756	1140.40
34	900	800	800	800	845	804	1210.56
35	961	876	876	880	896	855	1282.82
36	1024	923	923	920	950	906	1357.17
37	1089	1029	1029	1030	1006	960	1433.60
38	1156	1068	1068	1070	1064	1015	1512.15
39	1225	1120	1120	1120	1124	1071	1592.80
40	1296	1204	1204	1200	1185	1129	1675.52
41	1369	1272	1272	1270	1248	1188	1760.40
42	1444	1343	1343	1340	1312	1249	1847.26
43	1521	1396	1396	1400	1377	1312	1936.26
44	1600	1480	1480	1480	1448	1375	2027.38
45	....	1518	1518	1520	1512	1441	2120.53
46	1764	1587	1587	1590	1581	1508	2215.87
47	....	1656	1656	1660	1652	1577	2312.20
48	1936	1728	1728	1730	1724	1647	2412.74
50	2116	1872	1872	1870	1872	1791	2618.00
52	2304	2025	2025	2020	2025	1942	2831.63
54	2500	2184	2184	2180	2184	2099	3053.63
56	2704	2350	2350	2350	2350	2262	3284.02
58	2916	2524	2524	2520	2524	2431	3522.78
60	3136	2704	2704	2700	2704	2606	3769.92

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VENEER PLANT LOCATIONS

The preceding description of veneer manufacture would be incomplete without some information as to usual veneer plant locations. In general, one veneer operator makes plain veneer, mostly rotary, while another devotes his attention to figured face veneer, chiefly sliced. It is seldom that both are produced at the same plant, due to the fact that intensive production methods must prevail to secure economy in a plain rotary-veneer unit, while in a figured-face veneer operation the quality of the product is the dominant motive, and quantity production is quite secondary. Many, but not all, of the leading centers for face veneer production are on the seaboard or waterways, to accommodate imported logs. The principal points are Boston, New York, Norfolk, Pensacola, Memphis, St. Louis, Louisville and Chicago and other scattered places.

On the other hand, rotary-veneer plants, where both raw material and finished product have a much higher ratio of bulk to value, are apt to be placed at an advantageous location to obtain logs, provided such location is not too inconsistent with convenient marketing.

These rotary-veneer plants are located, more or less, according to the species or groups of species that are cut. The New England, Adirondack and Wisconsin areas specialize in birch and maple. Poplar grows best in the Appalachian region, and many veneer plants are in that district. It is claimed that the best oak grows in Indiana. Veneer plants producing the various types of gum veneer are mostly in the southern states.

It is estimated that approximately half of the plywood plants in the United States have their own lathes for veneer cutting, usually in their main plant, but sometimes in the timber areas. Other independent veneer plants, making single-ply exclusively, serve both the plywood manufacturer and the furniture manufacturer who fabricates, rather than buys, his own plywood. Such single-ply plants are usually near the timber. Relatively few furniture factories have their own plywood departments, and those are among the largest.

The veneer plants producing Douglas fir, pine and spruce are found principally in the Pacific region. The cutting of veneer and the making of plywood usually are combined in these species. These kinds of veneer seldom are marketed except in plywood form.

Some plywood plants cater largely to the construction trades direct, through wholesalers, brokers and warehouses.

While this treatise is concerned principally with veneer that is converted into plywood, there is a large quantity of single-ply veneer cut and made into berry boxes, hampers, baskets, crates and the like. There are also a considerable number of minor industrial uses for various kinds of veneer.

WOOD CHARACTERISTICS

There are a number of publications, listed in the Bibliography on page 344, that describe fully the botanical and physical characteristics of the various species of wood. Photographic reproductions are also available to assist in the identification of these species.

The recent (1941) excellent summary, published by the Veneer Association of Chicago, is included here, by the permission of its sponsors. It gives a concise outline of the essential facts about utilizing and identifying most of the woods, but with particular reference to evaluating foreign and domestic face veneers.

The veneers listed below, known as "face veneers," are those used for the exposed surfaces of furniture, architectural panels, etc.:

Notes

(1) **Botanical Name:** Often various species are known by the same commercial name. The botanical name serves further to identify the species which is being described. Where several species are known by the same commercial name, that used most often in the form of veneers is listed.

(2) **Price Range:** The classifications, "low," "low-medium," "medium," "medium-high" and "high," are approximate, and are to be used only for the purpose of comparing the price of one species with that of another.

These classifications have been based on medium-grade stock of average figure (where figure is available). Plain veneers of the same species would average less, highly figured veneers, more.

(3) **Hardness:** The various species are described as "soft," "soft-medium," "medium," "medium-hard," and "hard," so that they may be compared with one another. "Soft" does not mean botanically soft. Wherever possible, recognized test figures have been used as a basis for classifications. Tests were not available for all species; it was necessary to resort to good judgment.

(4) **Veneer Sizes:** To be used with caution. These are approximate maximum sizes commercially available, but not necessarily always obtainable. The column entitled "Cut" indicates whether the size refers to quartered-sliced ("Qtd."), flat-cut ("Flat"), half-round ("H. R.") or full-rotary longwood veneers ("Rot.").

Maximum length, when 16 feet, is for knife-cut veneers. Sawn veneers may run longer. Standard thickness of American knife-cut face veneers is 1/28 inch.

* Indicates the species may be had in LUMBER.

** Indicates: (a) Small quantities of LUMBER are available, or, (b) The species may be had in SOLID FORM, for novelties, etc.

Commercial Name	Botanical Name (1)	Origin	Color Range	Types of Figures Available	Price Range (2)	Hardness (3)	Approximate Max. Veneer Sizes (4) Cut	Width	Length
**AMARANTH	Peltogyne paniculata	The Guianas	Purple	Generally straight grained and plain. Occasionally wavy or roey.	High	Hard	Qtd. Flat	9″ 18″	12 ft. 12 ft.
*ASH, Amer.	Fraxinus nigra and Fraxinus Americana	U. S. A.	White to light brown	Qtd. usually fiddleback if figured. Growth rings are pronounced in all types of veneer. A few crotches. Some burls.	Med.-High	Med.	Qtd. Flat Rot.	9″ 18″ 36″	12 ft. 12 ft. 10 ft.
ASH, Jap. (Tamo)	Fraxinus sieboldiana	Japan, Korea	White to light brown	Curly, fiddle, mottle, and "peanut." Most veneers cut in U. S. are highly figured.	High	Med.	H. R.	24″	7 ft.
ASPEN	Populus alba	U. S. A.	Light straw	Plain to heavy cross-fire. Has a velvety appearance. A few crotches.	Med.	Soft-Med.	Qtd. Flat Crotch	10″ 20″ 11″	14 ft. 14 ft. 36″
**AVODIRE Longwood	Turraeanthus Africana	Africa	Milky white to cream	Plain stripe, broken stripe, roll or rope.	Med.	Soft-Med.	Qtd.	15″	16 ft.
Crotch	"	"	"	Swirl or feather.	High	Soft-Med.		16″	4 ft.
AYOUS	Triplochiton scleroxylon	Africa	Pale straw to yellow	Usually ribbon stripe.	Low-Med.	Soft	Qtd.	16″	16 ft.
*BIRCH	Betula lutea and Betula lenta	North America	White to light reddish brown	Wavy or curly grained. Flat cut, generally figured; rotary, plain. A few burls.	Low-Med.	Med.-Hard	Qtd. Flat Rot.	9″ 18″ 36″	16 ft. 16 ft. 10 ft.
**BOSSE	Guarea cedrata	Africa	Pinkish to light reddish brown	Well figured. Roey, or curly.	Low-Med.	Med.	Qtd.	16″	16 ft.
**BUBINGA	Copaifera, aff. Tessmannii	Africa	Pale to deep flesh red, with thin dark lines	Plain to well figured. Straight stripe, broken stripe, mottle. Also shell cut. Figure stands out better when finished.	Med.	Hard	Qtd.	18″	16 ft.
**BUTTERNUT	Juglans cinerea	U. S. A.	Very pale gray-brown	Usually plain. Appearance is similar to that of American walnut, except for color.	Med.	Soft	Flat H. R.	14″ 18″	12 ft. 8 ft.
*CEDAR, Aromatic Red	Juniperus virginiana	U. S. A.	Heart: red to pink Sap: cream	Knotty.	Low	Med.	Flat	10″	10 ft.

Commercial Name	Botanical Name (1)	Origin	Color Range	Types of Figures Available	Price Range (2)	Hardness (3)	Approximate Max. Veneer Sizes (4)		
							Cut	Width	Length
*CHERRY (black)	Prunus serotina	U. S. A.	Light to dark reddish brown	Slight figure. Burl. A few crotches.	Low-Med.	Med.	Flat H. R. Rot. Qtd.	20" 24" 36" 10"	16 ft. 10 ft. 10 ft. 16 ft.
**EBONY, Macassar	Dyospyros sp.	Dutch East Indies	Rich, black-brown with medium tan, orange or yellow markings	Contrasting stripes due to pigment coloring.	High	Hard	Qtd.	9"	10 ft.
ELM, Carp. (Burl)	Ulmus campestris	Europe	Light reddish brown	Varies from small compact figure to wild, grainy figure.	High	Med.-Hard		24"	4 ft.
FAUX SATINE (Cypress Cr.)	Taxodium distichum	U. S. A.	Amber to golden	Small, feather crotch figure.	High	Soft		12"	6 ft.
*GABOON (Okoumé)	Acoumea klaineana	Africa	Golden to pinkish tan	Plain, wavy, curly, or rope figure. Crotch.	Low-Med.	Soft-Med.	Qtd. Crotch	18" 22"	16 ft. 6 ft.
*GUM, RED	Liquidambar styraciflua	U. S. A.	Heart: brown tinged with pink Sap: grayish white	Plain; medium to highly figured with chocolate markings.	Low	Soft-Med.	Qtd. Flat Rot.	12" 20" 36"	16 ft. 16 ft. 10 ft.
**HAREWOOD, Eng. Gray Eng. White	Acer pseudoplatanus	England	Eng. Gray: Silver gray, turns to tannish gray Eng. White: Cream to white	Plain, curly, fiddleback, finger-roll, or heavy cross-fire.	High	Med.-Hard	Qtd. Flat H. R.	10" 20" 22"	12 ft. 12 ft. 10 ft.
**HOLLY	Ilex opaca	U. S. A.	White	Plain.	Low-Med.	Med.	Flat	12"	10 ft.
KELOBRA	Enterolobium cyclocarpum	Mexico & Central America	Brown, sometimes shaded with reddish tan	Plain striped, large pores. Crotch.	Low-Med.	Soft-Med.	Qtd.	18"	12 ft.
**KOA	Acacia koa	Hawaii	Golden brown to red-brown, shaded	Plain, curly, fiddleback. Some stumpwood.	Med.	Med.	Qtd. Flat	16" 27"	14 ft. 14 ft.
LACEWOOD	Cardwellia sublimis	Queensland, Aus.	Pink to light, leather brown	Small to large "flake."	Low-Med.	Soft-Med.	Qtd.	18"	16 ft.
*LAUAN (Red and White)	Shorea negrosensis Pentacme contorta	Philippines	Whitish to dark red-brown	Plain, ribbon stripe.	Low	Med.	Qtd.	16"	16 ft.
**LAUREL, E. I.	Terminalia tomentosa	India	Dark brown, with darker streaks	Plain, ripple, stripe.	Med.-High	Hard	Qtd. Flat	9" 16"	12 ft. 12 ft.

Commercial Name	Botanical Name (1)	Origin	Color Range	Types of Figures Available	Price Range (2)	Hardness (3)	Approximate Max. Veneer Sizes (4)		
							Cut	Width	Length
MADRONE (Burl)	Arbutus menziesii	California & Oregon	Light reddish brown	Clean burls and swirls, sometimes spotted with deep red.	Med.-High	Hard		36"	48 "
MAHOGANY *African	Khaya ivorensis	Africa	Pale salmon when first cut. Darkens with age.	Plain stripe, narrow or broad broken stripe, large and small mottle, fiddleback, blister and plum-pudding, rope, and combinations of these figures.	Plain Low Fig. Med.	Soft-Med.	Qtd. Flat H. R.	24" 27" 30"	16 ft. 16 ft. 10 ft.
*Cen. & South America	Swietenia macrophylla	Cen. & So. Amer.	Light sherry when first cut. Darkens with age.	Predominantly plain stripe. Occasionally same figures as available in African Mahogany.	Plain Low Fig. Med.	Soft-Med.	Qtd. Flat	15" 24"	16 ft. 16 ft.
*Cuban & Santo Dom.	Swietenia mahagoni	W. Indies	Yellowish white when first cut. Darkens to light golden brown, or sometimes a deep, rich, brown-red.	Same figures as available in African Mahogany. Frequently two or more types of figures are combined.	Plain Med. Fig. Med.-High	Med.-Hard	Flat H. R. Qtd.	24" 24" 10"	12 ft. 10 ft. 12 ft.
Faux Swirls	All mahoganies		Light to dark reddish brown	Swirl effect.	Med.	Med.-Hard		30"	6 ft.
Crotches & Swirls	"		"	Moon and feather crotch. Plain and figured swirl.	High	Med.-Hard		24"	10 ft.
*MAPLE	Acer saccharum	No. Amer.	White to light pinkish brown	Plain, curly, bird's-eye, blister, fiddleback. Burls. Quilted (Acer macrophyllum).	Med.	Hard	Rot. Qtd. Flat	36" 9" 24"	10 ft. 16 ft. 16 ft.
**MYRTLE Cluster	Umbellularia californica	California & Oregon	Cream to tan, sometimes with darker burl	Burl or cluster. Cluster is mixture of plain wood, cream to light tan, and burl, which varies from tan to dark brown or black.	Med.-High	Med.-Hard		30"	10 ft.
Burl					High	Med.-Hard		30"	30"
NARRA	Pterocarpus indicus	Philippines	Pale yellow to salmon, to deep red	Stripe, broken stripe, roey, mottle, etc.	Med.-High	Med.-Hard	Qtd.	10"	14 ft.
**NEW GUINEA WOOD	Dracontomelum mangiferum	Papau, New Britain, Oceania	Brown to light gray with definitive black lines	Plain to highly figured. Plain stripe, figured striped, mottled.	Med.-High	Med.	Qtd.	10"	16 ft.

Commercial Name	Botanical Name (1)	Origin	Color Range	Types of Figures Available	Price Range (2)	Hardness (3)	Approximate Max. Veneer Sizes (4) Cut	Width	Length
*OAK, Native Plain	Red: Quercus borealis White: Quercus alba	U. S. A.	Light brown to reddish brown	Figure formed by prominent medullary rays. Coarse grain.	Low	Med.-Hard	Flat	24"	16 ft.
Qtd.	"	"	"	"Rift sawn", pin stripe, flake (Native Oak also available in Burls).	Low-Med.	Med.-Hard	Qtd.	12"	16 ft.
*OAK, Eng. Brown	Quercus sessiliflora	England	Nut brown to deep brown	Plain or streaked, with a flake figure. Burls (incl. Tortoise Shell).	High	Med.-Hard	Qtd. Flat	12" 20"	16 ft. 16 ft.
"OAK," Tas. (Yuba)	Eucalyptus sp.	Australia	Tan	Fiddleback.	Med.	Med.-Hard	Qtd. Flat	10" 20"	16 ft. 10 ft.
**ORIENTAL-WOOD	Endiandra palmerstoni	Australia	Brown, with lavender gray or greenish gray to salmon cast	Stripe, strong stripe, mottle, fiddleback, roll.	Low-Med.	Hard	Qtd.	16"	16 ft.
**PADOUK, Afr. Burma Vermilion	Pterocarpus soyauxii " macrocarpus " dalbergioides	Africa Burma Andamans	Golden red to deep crimson	Wide parallel stripe, narrow broken stripe, mottle, finger-roll, fiddleback, curl.	Med.-High	Hard	Qtd. Flat	14" 20"	16 ft. 16 ft.
**PALDAO	Dracontomelum dao	Philippines	Variable. Tan background with brown to black streaks	Stripe and mottle. Figure caused by concentric bands. A few crotches.	Med.	Hard	Qtd. H. R.	12" 24"	16 ft. 10 ft.
*POPLAR	Liriodendron tulipifera	U. S. A.	White to yellow	No definite figure. A little curly; some blister; some burls.	Low	Soft	Qtd. Flat	12" 27"	16 ft. 16 ft.
**PRIMA VERA	Cybistax Donnell-Smithii	Cen.Amer. & Mex.	Cream	Broken stripe, mottle, fine feather grain. Crotch and Swirl.	Med.	Soft-Med.	Qtd. Flat	12" 20"	12 ft. 12 ft.
**REDWOOD Burl	Sequoia sempervirens	California	Reddish brown	True Burl.	High	Soft		36"	4 ft.
*ROSEWOOD, Brazilian	Dalbergia nigra	So. Amer.	Red to brown, streaked with black lines	Wide range of figures caused by pigment coloring. Includes "bar" figure. Very few crotches.	High	Hard	H. R. Flat Rot.	24" 18" 28"	10 ft. 14 ft. 10 ft.
**ROSEWOOD, E. I.	Dalbergia latifolio	India, Ceylon	Variable — purple to straw, striped	Pin and ribbon stripe. A few feather crotches.	Med.-High	Hard	Qtd.	12"	16 ft.
**SAPELI	Entandrophragma cylindricum	Africa	Med. to dark brown	Pronounced straight, broken, or ribbon stripe. Occasionally a slight cross figure.	Low-Med.	Med.-Hard	Qtd.	24"	16 ft.

Commercial Name	Botanical Name (1)	Origin	Color Range	Types of Figures Available	Price Range (2)	Hard-ness (3)	Approximate Max. Veneer Sizes (4)		
							Cut	Width	Length
**SATINWOOD	Chloroxylon swietenia Zanthoxylum flavum	Ceylon, West Indies	Cream, to rich golden yellow	Nearly all more or less figured. Stripe, cross-fire, roey, wavy, mottled.	High	Hard	Qtd. Flat H. R.	10" 20" 24"	16 ft. 16 ft. 10 ft.
*SYCAMORE (Native)	Platanus occidentalis	U. S. A.	Tan to pinkish brown	Prominent flake figure. Ribbon stripe.	Low	Soft	Qtd.	14"	14 ft.
*TEAK	Tectona grandis	Burma, India	Golden brown, darkening with age	Plain, ripple, mottle. Sometimes nicely figured.	Med.	Med.-Hard	Qtd. Flat	16" 24"	16 ft. 16 ft.
THUYA (Burl)	Tetraclinis articulata	Algeria	Deep reddish brown	Figure consists of small, distinctive "eyes."	High	Med.		24"	24"
**TIGERWOOD	Lovoa klaineana	Africa	Golden brown	Ribbon stripe. Blister. "Snail" figure. Crotch.	Low	Soft-Med.	Qtd.	16"	16 ft.
WALNUT, Amer. *Plain Longwood	Juglans nigra	U. S. A.	Soft gray-brown, sometimes shaded with darker brown	Plain stripe, pencil stripe. Typical "flat cut" or rotary figure, without cross-fire.	Low	Med.	Qtd. Flat Rot.	10" 20" 32"	16 ft. 16 ft. 10 ft.
**Figured Longwood	"	"	"	Mottle, fiddleback, figured striped, rope figure.	Med.	Med.	Flat Qtd. H. R. Rot.	20" 10" 24" 32"	16 ft. 16 ft. 10 ft. 10 ft.
**Stumpwood	"	"	"	Plain and figured.	Med.-High	Med.		28"	42"
**Crotches & Swirls	"	"	"	Swirl or feather crotch; plain or figured swirls.	Med.-High	Med.		15"	36"
Burls	"	"	"	Burl.	High	Med.		24"	24"
WALNUT, Claro	Juglans sp.	California	Light to rich brown, streaked	Characteristic wide black banding. Plain, mottle, wavy. Crotches.	High	Med.	Qtd. Flat	14" 18"	10 ft. 10 ft.
**WALNUT, Fr., Eng. & Circas.	Juglans regia	Europe	Nut brown to dark brown	Various streaked and swirly effects. Stumpwood. A few crotches. Some burls.	High	Med.	Flat H. R.	20" 20"	10 ft. 10 ft.
**ZEBRAWOOD	Brachystegia spp.	Africa	Creamy yellow, with prominent dark brown or black stripes	Narrow stripes, from 1/4" to 1/2" apart. Some shell cut.	Med.	Med.	Qtd.	12"	16 ft.

QUESTIONS

1. In how many ways is veneer produced, and what are they?
2. What are the outstanding advantages of rotary veneer? of sliced? of sawn?
3. Why are veneer logs cooked and how?
4. Discuss operating speeds and veneer delivery on rotary lathes.
5. What is meant by loose and tight cutting?
6. How does slicing differ from rotary cutting?
7. Describe a flitch, before and after cutting into veneer.
8. How is face veneer sampled and marked?
9. Describe why and how a log is quartered.
10. What is the relation of half-round veneer to rotary and sliced?
11. What method and equipment are used for sawn veneer?
12. Discuss the character and cost of sawn veneer.
13. Describe the principal types of veneer driers.
14. What is a log scale, and how did they develop?
15. Why does veneer cutting (rotary) overrun the scale?
16. Discuss the problem of veneer plant location.

Describe briefly the characteristics of the following species:

17. Birch.
18. Gum.
19. Mahogany, with particular reference to figured faces.
20. Oak, red and white.
21. Poplar, the general utility wood.
22. Walnut and its various face cuttings.

SECTION SIX

PLYWOOD MANUFACTURING

SCOPE OF OPERATIONS

The manufacturing operations that distinctly belong in the plywood group are as follows:

- Veneer Preparation
  - Plain veneers for crossbands, backs and rotary cores
  - Face veneers
- Making Lumber Cores
- Gluing Department
  - Cold pressing
  - Hot pressing
- Plywood Finishing
  - Dimensioning
  - Sanding

In addition to a complete description of these operations, several other collateral subjects are included:

- Reinforced Faces
- Resin Bonding without Hot Presses
- Electrostatic Heat for Resin Bonding
- Flexible-bag Pressures

These may, or may not, be included in any regular plywood factory, since these products and processes are rather highly specialized.

Plywood factories vary widely in the scope of their operations, some including the cutting of veneer, and others making the plywood into its final product, such as furniture. In other instances the management, which may have elected to specialize in all-veneer constructions, prefers to purchase, from outside sources, its limited requirements in lumber cores.

Hence, this section will include the essential plywood steps from the time the veneer is cut, ready for sale or remanufacture, until the plywood is completed through any of the various manufacturing processes that are likely to be used. Since the flexible-bag pressure technique is a combination of veneer assembly into plywood, and in addition, fabrication beyond the normal plywood stage, it will be so treated in the text.

PREPARING VENEER FOR PLYWOOD

So far, the manufacture of veneer has been treated as an independent and more or less complete product, converted from nature's resources, the trees, for later sale to and use by plywood manufacturers. Its production has been carried to the point where it was ready and suitable for storage or shipment. From here on, this product, veneer, is visualized as a raw material entering the plywood or furniture factory for further processing as an integral part of plywood. The situation is somewhat similar to leather, which is an intermediate product used eventually for shoes, belts, harness or bags; or to pig iron or billet steel, which later appear as further developed products.

The typical plywood factory or department which, for the sake of simple illustration, does not produce any of its own veneer, receives its face veneers from one or more sources, sampled, selected and bought in flitches. Plain or commercial veneer, where figure is unimportant, comes from still other sources, and is usually dimensioned to the buyer's specifications and sizes. Both kinds of veneer have been dried down to about 10% M.C., and can be stored safely for an indefinite period. Such a plywood factory is apt to be in a location favorable to the marketing of its products, where skilled labor is available and living expenses are reasonable. Such a typical plywood factory will have two veneer preparation departments, one for figured faces, where skill, experience and artistic ability are needed; and the other for plain veneer, in which the emphasis is laid on sound veneer that will make a good foundation and sturdy backing for the figured faces. This latter department will have its success measured by the quantity of acceptable product delivered, while the former is responsible for the quality that will encourage the sale of the artistic, attractive and appealing ultimate product into which the plywood is built—furniture, radios, pianos, cabinets, etc.

Plain Veneer Department

The more conventional term applied to this department is **Backs and Bands.** It prepares the plain veneer required for crossbands, for backs (unless the plywood has two faces, as a buffet door) and for rotary cores. The veneer is received, usually cut to dimensions, with adequate allowances for trimming after being made into plywood. It is seldom that logs yield all the desired veneer in whole sizes; usually about 50% is in **wholes** (1-piece), and the remainder in **halves** (2-piece), **thirds** (3-piece) and **quarters** (4-piece), etc. Sometimes random widths are

allowed, or are inevitable if sizes have to be cut down from larger available sheets. The various inner layers of all-veneer constructions are usually included in this department. While certain products, like die-cutting blocks, are commonly made of all-veneer layers, other mills use the all-veneer construction in lieu of lumber cores. The following steps are applicable to crossbands, backs, rotary cores, and all-veneer constructions, unless otherwise indicated.

Redrying and Flattening

Most of this plain veneer is received somewhat wrinkled, and at approximately 10% M.C., sometimes considerably wetter if exposed in shipment. The first step is **redrying** and **flattening**, in a plate redrier of the type shown in Fig. VI. 1. This is a series of hollow cast iron plates or platens, with flat planed surfaces. Live

Courtesy, Merritt Eng. & Sales Co.

Fig. VI. 1—Plate redrier.
Operating on plain sliced walnut-face veneer.

steam, at 75 to 100 pounds, is supplied to each plate and the only pressure exerted on the veneer for flattening during drying is that of the top plate which rests on the bottom plate of each pair. In the upper pair of plates the veneer is drying and flattening, there being an intermittent lifting of the top plate for **breathing**, since continuous pressure would cause the veneer to split as it shrinks in drying under pressure. The space between the second and third

plates is open, for loading and unloading, while three and four are closed as in the case of the upper pair, and so on down. When the open spaces are emptied of dried veneer, and fresh undried veneer is inserted, the machine is reversed by the lever shown at the right. These new openings are then emptied and filled, while the closed openings are breathed, and so the cycles continue alternately. Several layers of veneer are inserted in each opening, approximately 5 of 1/28 inch, 4 of 1/20 or 1/16 inch, down to 1 of 3/16 or ¼ inch. The veneer should be left under alternate pressure long enough to come down to 5% M.C. or less.

Clipping and Jointing

This dried and flat veneer, if it is full size, is cooled and then is ready for plywood assembly. If it is fractional sizes, the edges must be **clipped** straight and true, preparatory to taping, to a size which allows for the final trimming of the plywood. The clipping operation, on a scissor-type machine, is sufficient for any interior or the back layer of the plywood. If it happens to be a plain face, it is necessary to **joint** the edges. A jointer, with a multi-knife rotary head, planes the edges of the veneer in packages about 2 to 4 inches thick, which packages are clamped firmly together during the jointing operation. An alternate method is to clip the edges of the fractional sheets on a guillotine cutter, as described under face-veneer preparation.

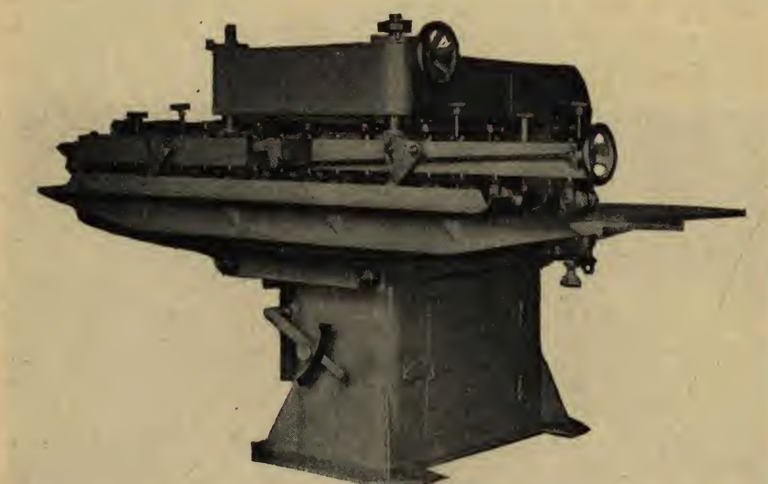
Fig. VI. 2—Veneer taping machine.

Taping Veneers

The veneers, that are halves or less in size, are fastened together with gummed paper tape, as shown in Fig. VI. 2. The dry gummed tape on the spool above passes through a moistening device to dampen the gummed side, and then passes down under the rollers and on the veneer. The roller shafts are angled to draw and hold the veneer edges closely together. The rollers are electrically heated to dry the gummed tape, while still under pressure. The operator at the right is feeding two single strips of veneer against a thin central guide, and the off-bearer at the left separates the taped sheets by a slight jerk, breaking the tape. The tape for inside layers is perforated, for better plywood adhesion, while that for the backs and faces need not be, as this outside tape can be sanded off.

Tapeless Splicers

This is a recently developed device, rapidly coming into general use, that glues the veneer, edge to edge, and eliminates the use of



Courtesy, Plycor Co.

Fig. VI. 3—Tapeless veneer splicer.

The long series of angling rollers and a heated spring plate keep the veneer edges from "riding" on each other.

gummed tape. It not only saves the cost of the tape, but also largely reduces the final sanding after the plywood is completed. It has a distinct advantage in water-resistant plywood, where the tape on the inner layers becomes a weakness in the plywood joint. This tapeless splicer is quite similar to the standard taping machine and is

shown in Fig. VI. 3. In one type of tapeless splicer, the veneer sheets have glue applied to both edges while under pressure in the jointer, by means of an added glue roller. This applied glue is partly dried and remoistened on the tapeless splicer by a suitable solvent. In some types of tapeless splicers, the adhesive is applied just ahead of the heating rollers.

Tenderizing Rotary Veneer

Rotary-cut veneer, when dried, tends to recover its curved shape, i.e., to curl back to the cylindrical shape in which it originally lay in the log. If it is not reasonably straight grained, it is likely to twist into irregular spiral shapes, due to the fact that all shrinkage in drying is widthwise of the veneer, at right angles to the grain at any spot. This tendency to distort may be temporarily neutralized when veneer layers are bonded together into plywood, but eventually such distortion tendencies in the inner layers are likely to reappear. Such stresses often become evident when plywood is cut apart, or when varying atmospheric conditions occur from time to time, or from side to side of the plywood. Each veneer layer contributes to plywood stability by its unchanging dimension along its grain direction.

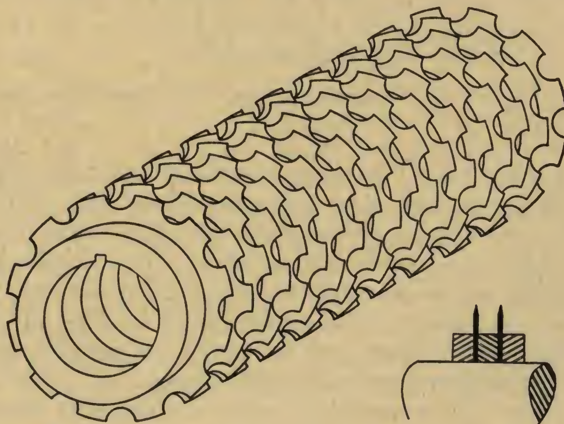


Fig. VI. 4—Slitting cutters for tenderizing veneer.
To be mounted on a pair of revolving shafts, with adjustments both for thickness of veneer and depth of cut.

Theoretically, the opposed grains in the adjacent layers of veneer will restrain, or at least retard, the widthwise shrink and swell, but it does not always work out completely in practice. In general, the theory works out reasonably well, but the exceptions are sufficiently

troublesome to require a remedy. The problem, in the last analysis, becomes one of reducing the widthwise power of the inner and unseen layers of veneer, so that its normal "come and go" is greatly lessened. One method is to specify loose cut or somewhat shattered veneer, but this still leaves a tight side, and the loose cutting varies according to log diameter and wood texture. Another method that is coming (1940) into general use is mechanically to cut intermittent regular slots on both sides of the veneer, to the point where the veneer is very limber and is loosely held together sidewise, but is still firm enough for convenient handling. The result of this method is

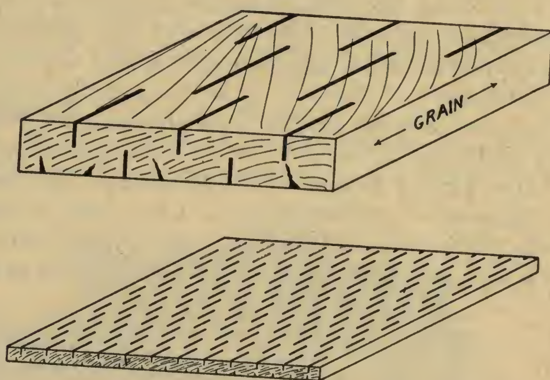


Fig. VI. 5—Tenderized veneer, with intermittent slots.

shown in Fig. VI. 4, detailing a series of circular slitting knives, with alternate cutting edges and gaps. Two such series would be required, on an upper and lower shaft, so that veneer can be passed between them and receive slots on both sides. Vertical adjustments of the shafts will accommodate varying depths of cuts in different thicknesses of veneer. The upper sketch in Fig. VI. 5 shows an exaggerated cross-section, and the lower, the general appearance of such a sheet of slotted or tenderized veneer.

While this slotting procedure will be of the most benefit on thick (1/8 to 1/4 inch) veneer in plywood cores, or multi-ply constructions, it will also be found helpful on crossbands and any other veneer layers.

Some prefer to do this slotting on the veneer immediately after drying and flattening to facilitate better jointing and taping. Others find that they secure better results after taping, to neutralize the cramping effect of the tape.

Ready for Plywood

These plain veneers are now ready to be stored in the air-conditioned room, adjacent to the plywood presses, where their moisture content is brought to or maintained at the proper point for plywood assembly. All items required for a plywood order should be ready a day or more ahead of pressing, to permit this conditioning, as well as to avoid any processing delays.

Figured Face Veneer Department

This is the department in a plywood factory where real artisanship is imperative, demanding workmen who can visualize in advance a beautiful and artistic veneer face, while looking at a flitch of figured veneer still in its original irregular shape. Highly figured face veneers may cost from ten to twenty cents per square foot, and yields are often between 25 and 40%, so that labor costs in this department are usually far less than the material factor.

Drying and Flattening

This operation closely resembles that for plain veneers on page 134, except in the case of highly figured and wrinkled veneer, which is often in the upper ranges of the cost scale. The platen drier is much too severe, and would ruin such fragile veneers by opening wide checks. A preferred method, recognized by better plywood operators, is to place three or four thicknesses of the fragile veneer between large (36 by 96 inches) heated boards. These boards are heated in the plate drier shown in Fig. VI. 1, and the veneers are dampened by sprinkling. Alternate layers of veneers and hot boards are piled up into a package about three feet high. These are gradually weighted, clamped or screwed down, bit by bit, as the combined heat and moisture softens the veneer, making it less brittle and more pliable. These packages are usually left under pressure over night and sometimes the treatment has to be repeated. With experience and judgment the most difficult veneers can be brought into workable condition.

Toughening Fragile Veneers

Many experienced plywood manufacturers have adopted a process of making fragile veneers tougher or more leathery by dipping them in a liquid sizing or toughening solution, and then redrying them down to the customary 5% M.C. before further fabrication. This toughening is usually done on the rough, untrimmed veneer before

dimensioning. One satisfactory solution that has been widely used is as follows:

Water	63 parts
Animal glue	16
Alcohol	16
Glycerine	5
	100 parts

The animal glue and part of the water are heated together until well dissolved, other ingredients are added and thoroughly mixed. The veneers are immersed, stood on a drain board to drip, and finally dried down to the desired point. Several patented preparations of similar character are on the market, for those who prefer them.

Dimensioning

Figured flitch veneer is usually divided into two classes, with a somewhat vague line of demarkation between: **longwood** flitches of moderate figure, usually over six feet long, in which matching effects seldom go further than turning the alternate sheets; and **stumps, crotches, swirls, burls,** etc., that tend to be chunky and far more irregular and of lower yields than the longwood. The longwood is cut to length in packages an inch or more in thickness, and the sapwood on the edges is trimmed off. The more highly figured flitches are rough cut to size, with particular reference to centering or balancing the figure effects. Note the making of a four-piece matched, stump-figured, veneer face described on page 49. After carefully considering the specifications and the desired results, these rough-dimensioned face veneers are again trimmed in packages to true square edges and proper angles on a guillotine cutter, similar to a power paper cutter, with a shearing cut. This avoids tearing out the endy wood near the edges. Some plywood operators prefer to true the edges of longwood on the jointer described on page 135.

Taping or Tapeless Splicing

The veneer is now ready to join together, pair by pair, with frequent intermediate guillotine cuts to straighten the edges or equalize the angles. Where the face veneer is reasonably straight grained the tapeless splicer process is preferable, since it eliminates much sanding in the finished plywood. In diamond and "V"-matched joints, as well as in end joints and those of endy wood, it is necessary to use tape. It is desirable to avoid several layers of tape on top of each other, as this pile of tape may be pressed into the plywood and require excessive sanding. These machines are illustrated in Figs. VI. 2 and VI. 3.

Combination Faces, Inlays and Marquetry

These are more highly developed mechanical and artistic effects, with contrasting colors, angling grain and geometrical forms, built up step by step, as above, by highly skilled artisans. There are many ways to obtain the results and workmen are likely to develop many individual methods. An adequate description is too complex for the limited space available here.

Reinforced Two-ply Faces

Many of these complicated veneer faces require prompt reinforcement to forestall dimensional changes under varying conditions of moisture absorption, for safer handling, and sometimes for bending or curving around pilasters, into serpentine drawer fronts, and over curved doors. This is best done by bonding these fragile faces to a thin (1/40-inch) veneer backing of a strong, sturdy veneer, like birch, using a heat-reactive resin film like Tego. This bonding operation is described later on page 178. The use of a dry film does not expand the face veneer or open the joints, as a liquid glue is likely to do. The grain direction of the backing, in general, is perpendicular to the weakest direction of the face veneer, although sometimes an angling direction is preferable.

Ready for Plywood

Veneer faces, processed according to their requirements above, are now ready to be placed in the air-conditioned room, described on page 150. Their moisture content must be maintained at the proper point until assembled into plywood.

MAKING LUMBER CORES FOR PLYWOOD

Fundamentals

Lumber-core plywood, as contrasted with all-veneer constructions, is preferred for furniture, upright pianos, radios and many other similar types of cabinet plywood. Lumber cores are seldom used for plywood less than ⅝ inch thick, and the standard thickness for furniture requirements is 13/16 inch. Since such plywood is largely used for tops for tables, buffets, bureaus, commodes, and the like, 13/16-inch, 5-ply, lumber-core plywood is customarily called **top construction**, as contrasted with **panel construction** for thinner plywood, all-veneer layers, usually ⅜ inch or less, which may be mounted in grooved or rabbeted frames.

Since the lumber core is the dominant strength factor, comprising about 80% of the total thickness of the top, its construction is highly

important. Its function is twofold: to furnish a sturdy, firm base for the decorative face veneers, and to impart the necessary strength and stability to the cabinet of which it becomes an important structural part.

There is much available printed material on the selection and grading of lumber, as well as on its proper kiln drying and tempering. The machines for crosscutting, ripping and surfacing have been described adequately elsewhere and there is no need to repeat them here.

Types of Lumber Cores

Nearly every plywood manufacturer has his own pet individual construction for lumber cores, varying somewhat in rather unimportant details. They may be grouped in some half dozen principal types, as shown in Fig. VI. 6, and a brief description follows:

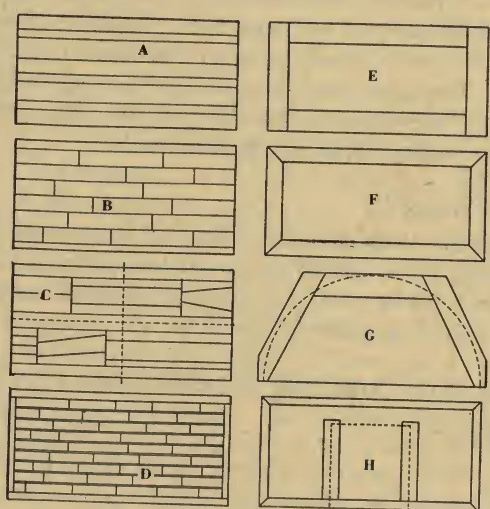


Fig. VI. 6—Types of lumber cores.
Lettered types described in the text.

A—Regular standard core, made of random-width core strips, none of which should be wider than 3 inches. Strips may have slightly tapering edges, instead of parallel, if such a plan increases the lumber yield.

B—Core with butted joints in the core strips. This tends to distribute twisting stresses, but requires uniform width strips. Appearance requires that the outside edge strips be continuous.

C—This core is made necessarily in two steps, first the smaller assembly, accurately dimensioned and then combined into a final core by full-length core strips. The dotted lines indicate how such a core may be made to anticipate cutting down into four smaller units after plywood is completed. This combination of four-in-one may be applied as well to types A and B. The labor cost of this type is usually prohibitive, except in certain woods, such as interiors for cedar chests.

D—Flush door cores are quite different from the three types above, which are standard in furniture. This door core is made of small blocks (cut-downs from sash and door trimmings) of white or sugar pine. The thin veneer strips, between the rows of blocks, are chiefly glue carriers, but since their use is patented, they are often omitted. In a door core of this type it is necessary to have hardwood edges and ends, both for appearances to match the door surfaces, and to protect the interior from moisture. The steps in construction are obvious: the center is made first; its ends trimmed square; the bottom and top rails are attached; the whole ripped to width and the side rails added last.

E—Railed or banded core for furniture, since an "ogee" shaping of regular plywood cores (A) would expose too much end core wood. The rails are usually of the species used for face veneers to allow consistent finishing. The illustration is railed on both edges and on both ends; there may be variants in railing both ends only, or both ends and one edge, where the other edge is not exposed to public view.

F—Slightly different from E, with rails mitred at all four corners. This is costly and not much used.

G—A special construction for semi-circular table tops, to reduce end wood exposure. This shape of table top at present is not much in favor. See also Fig. IV. 2.

H—Special construction for desk writing beds, providing for hinged cutouts to accommodate typewriter compartments.

While the above types are all used in the United States, there are two additional constructions that find favor in England and on the Continent, although their cost appears excessive here. They are shown in Fig. VI. 7. These cores are made up in large blocks of lumber or veneer to a thickness that represents the width of the final core. The blocks are then cut to proper thickness, along the dotted line, on a reciprocating gang resaw. Since most lumber is plain (rather than quarter) sawn, this method results in quarter-sawed cores, with narrow core strips, a construction that is highly prized for its non-warp qualities. When the block is made of rotary

veneer, it becomes an almost ideal construction, neutralizing all interior stresses, but it is costly.

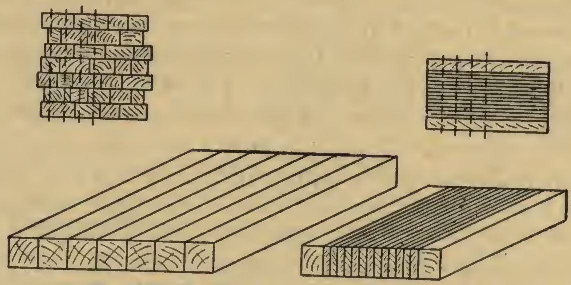


Fig. VI. 7—Block cores, to be resawed.

Core Joints

Again we find a difference of opinion among woodworkers, as to the most desirable type of core joint. Several are shown in Fig. VI. 8, and the principal points, pro and con, are enumerated as follows:

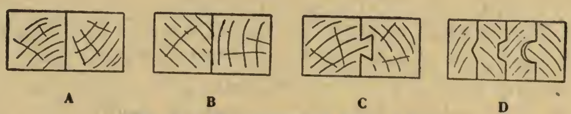


Fig. VI. 8—Types of core joints.
Lettered types described in the text.

A—Jointed or planed joint, making the line between two core strips as inconspicuous as possible. This is the highest grade of joint, but requires both ripping and jointing of both edges of all core strips.

B—Rip-saw joint that is quite satisfactory for most purposes, but may show slightly on a molded end.

C—Linderman joint, with dovetail tapering in such a manner as to draw the joint tightly together. About 10% of the lumber is wasted in cutting the dovetail tongue. At present, it is used mostly for solid lumber construction.

D—Various types of tongue and groove joints, all wasteful of stock, but serving to center and level the core strips when they are glued and clamped together.

Preparing the Core Strips

The lumber usually is cut to length first, and then ripped clear of defects, care being taken that no strips are more than 3 inches wide. In the case of cores with butted joints (Fig. VI. 6), the lumber is first ripped on circular gang rip saws, and clip sawed to lengths

afterwards, using all odd lengths. Lumber must be dried well and evenly to 5% M.C., and sometimes is rough planed before dimensioning, to reveal surface defects and grain direction more clearly.

The jointing or tongue and groove operation comes next, unless a saw joint is all that is required.

The matching table requires an operator with wood sense to arrange strips properly with a view to well-balanced stresses. A few examples of this wood sense are: of two strips ripped apart, one should be turned to distribute the stresses; soft and hard textured strips should not be neighbors; and cross-grained strips should be balanced against each other. Few woodworkers appreciate the importance of such discrimination on the matching table. Most matching tables have a rip saw to cut cores to width, leaving these saw cuts on the outsides of the edge strips in the completed cores.

Venting Railed Lumber Cores

The regular standard lumber core, shown in Fig. VI, 6A, is not likely to cause any difficulty in hot pressing, even if some core strips unintentionally may have excess moisture above the normal 5%.

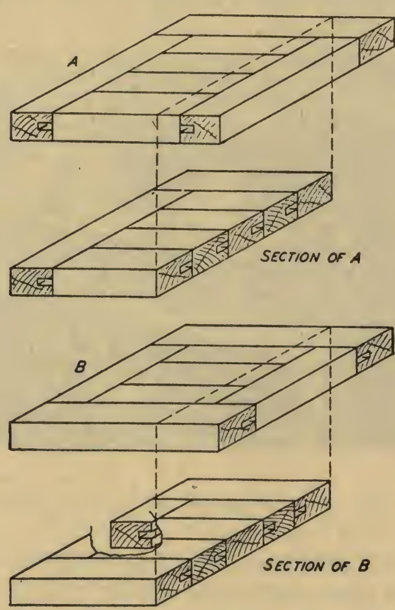


Fig. VI. 9—Banded lumber cores.

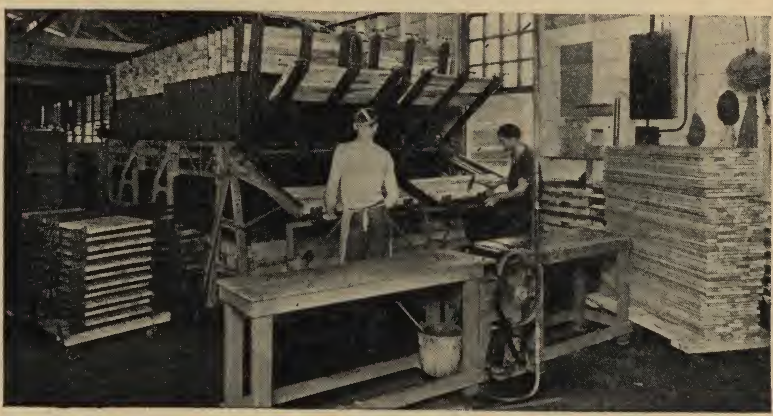
Vent slots release imprisoned moisture. These slots are intercommunicating and their outlets can be plugged with standard thicknesses of veneer. The upper construction, *A*, banded three edges, need not be plugged unless the rear edge is exposed.

However, in railed or banded cores, Fig. VI. 6E, the conditions are quite different, since this excess moisture is definitely imprisoned by the end core rails or bands. Such excess moisture, if it is sufficient, may cause a steam pocket that will rupture the plywood as it is removed from the hot press.

An approved and demonstrated method of avoiding this difficulty is to edge groove the core strips, before clamping them together, as shown in Fig. VI. 9. The upper sketch shows a core banded on both ends and one edge, and the lower a four-side railed construction. The grooves can be seen to be intercommunicating, so as to release such excess and impounded moisture. If the grooves are cut to a suitable width and depth, the open ends can be plugged with veneer, as shown in Fig. VI. 14, while if the open ends of the grooves are not exposed, this plugging may be omitted.

Revolving Clamps

These machines, shown in Fig. VI. 10, have a series of single or double clamp wings, hinged on an endless chain, that carries the clamps toward and away from the operators, and allows a 30-minute cycle for the glue to set under edge pressure. In the foreground of



Courtesy, Jas. L. Taylor Mfg. Co.
Fig. VI. 10—Revolving clamp carrier.

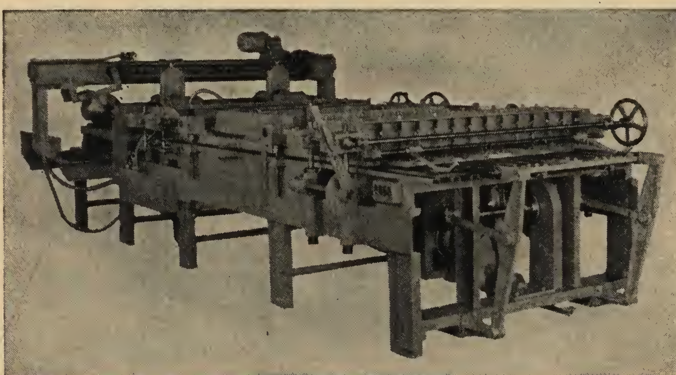
the illustration is a glue roller. Two operators are shown finishing the clamping of a fresh core; the operator in front of the window is just hammering some core strips down flush. This forcing of core strips is somewhat hazardous, especially if the core strip is twisted, since the building in of such stresses is likely to cause warp or

twist in the finished plywood. If the core strips have been tongued and grooved, they will be largely self-centering in the clamp.

At the left in the illustration is a pile of rough core blanks in hand clamps that some woodworkers prefer to the revolving clamps, and that are necessarily used on cores too large for the revolving clamps.

Core Assembly with Resin Adhesives

A recent development (1941) is an automatic core-assembling machine for the use of resin adhesives. Core strips are successively



Courtesy, Plycor Co.

Fig. VI. 11—Lumber-core continuous-feed press.
Note feed end at right and automatic trim saw at left.

glued on one edge with a quick-set resin adhesive. The core strips are held tightly together by heavy springs, and are progressively pushed between heated plates that cure the resin to a sufficient extent in a couple of minutes. The bond is strong enough so that the blanks can be sawed apart, automatically, and handled without breaking. The resin cure is completed in the several hours that intervene before planing. Substantial reductions in man power and floor space are predicted for this machine as it gains wider use.

Banding or Railing Lumber Cores

The bands or rails on lumber cores, Fig. VI. 6 E and F, are simply additional core strips, glued on the rough but trimmed core blanks, after removal from the clamps and before surfacing. They are usually of the same species as the face veneer, thus avoiding the exposure of different species of wood on the surface and edges of the plywood. The end rails also permit better finishing, as the side wood

of the end rail is exposed, rather than the end wood of the core strip. End wood is difficult to finish to match side wood, as a large amount of stain and filler soaks into the open pores, and results in considerably darker shades of color.

Surfacing the Core Blanks

A frequent cause of trouble in lumber cores is the inadequate removal of glue water that accumulates just at the freshly glued joint between lumber-core strips. This can be shown graphically in Fig. VI. 12, where the upper sketch shows, in exaggeration, the initial

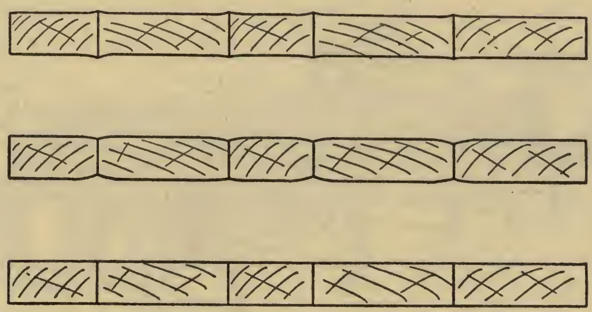


Fig. VI. 12—Drying glue water in core joints.

swelling of the wood in thickness just at the joint. If this glue water is not properly dried out or diffused throughout the core strip, before the core blank is surfaced or planed, the wood at the joints will shrink still further, and appear as slight trenches or sewers, as can be noted in the central sketch. If core blanks, piled with adequate ventilation, are allowed to dry for 24 to 48 hours after edge gluing and before surfacing, the result will be an even, uniform surface as shown in the lower sketch.

The proper technique for surfacing core blanks is well developed. The first surfacing should be a roughing cut on what is to be the face side of the core. The next surfacing can be on a two-side planer, making a thin or skin cut on the good side, and removing enough off the back to reduce the core blank to the desired thickness. If a double surfacer is not available, the second cut should be heavy on the back, followed by the skin cut on the face or good side.

Relieving Internal Stresses

If all the steps so far taken in core construction have been correct and accurate, the cores should produce flat and unwarped plywood.

However, most working conditions fall considerably short of the ideal, and extra precautions are well worth what they cost.

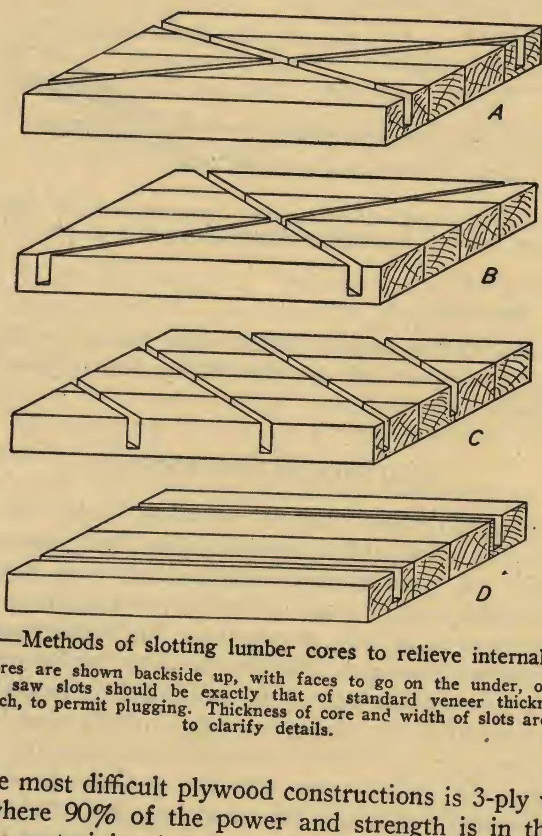


Fig. VI. 13—Methods of slotting lumber cores to relieve internal stresses. In all cases, cores are shown backside up, with faces to go on the under, or non-slotted, side. Width of saw slots should be exactly that of standard veneer thicknesses, 1/20-, 1/16- or 1/12-inch, to permit plugging. Thickness of core and width of slots are exaggerated to clarify details.

One of the most difficult plywood constructions is 3-ply with lumber cores, where 90% of the power and strength is in the lumber core, and the restraining influence of the face and back veneers is far less than in 5-ply. In spite of all the care that can be exercised, there is likely to be more or less incipient tendency to warp and twist in any lumber core, due perhaps to different textures in adjacent core strips or too much variation in moisture content.

A simple and practical way to relieve these internal stresses is shown in Fig. VI. 13, where various arrangements of saw slots can be cut on the back side of the core. These slots should extend about two thirds into the core, and should be of such width that they can be plugged with veneer strips as shown in Fig. VI. 14. If the plywood ends and edges are not exposed, it may not be necessary to do this plugging.

While this stress-relieving method of slotting is advocated especially for 3-ply lumber-core constructions, it is often found helpful in 5-ply constructions as well.

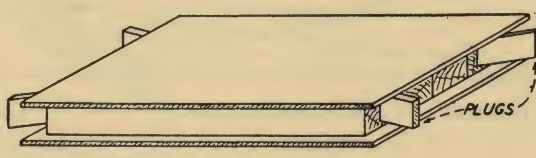


Fig. VI. 14—Showing method of plugging open ends of saw slots with strips of veneer, before trimming to dimension; applies to Fig. VI. 13A.

Ready for Plywood

The lumber cores are now ready to be placed in the air-conditioned storage room, ready for assembling into plywood with the veneers prepared as above.

GLUING DEPARTMENT

The preparation of the various plywood layers, of veneer and of lumber, has been fully described on the preceding pages. Theoretically, all parts should now be ready, on factory trucks properly tagged, and in matched sets, for the gluing operations. All of this material is best stored in an **air-conditioned room**, or a series of them, if several adhesive processes are in use. The purpose of this intermediate storage is twofold. It is partly to facilitate the gluing operations by having everything ready ahead of time, so that the glue-room crew is not handicapped by having to send out scouts to hunt for needed parts, and does not have to wait for previous departmental operations on minor missing items. The other purpose of this air-conditioned room is to maintain or bring all raw material to the most suitable condition for gluing. If temperature and humidity standards are established, as shown in the table, page 303, all wood parts can be brought to, and maintained at, the proper moisture-content equilibrium.

In the case of cold pressing with various liquid glues and liquid resins, this moisture content should be as low as possible, from 3 to 5%, so that the surplus moisture added by the glue solvent will cause the least trouble later when its removal is undertaken. In the air-conditioned room with a dry-bulb temperature of 90° F., the wet bulb should be around 60° to 65° F. In the case of hot pressing with resin film, the crossbands or other layers that produce the film

flow should approximate 10% M.C., requiring a wet bulb of 78° F., for a dry bulb of 90° F. However, the faces, as well as lumber and veneer cores for film gluing, should be kept down to 3 to 5% M.C. This combination may require two air-conditioning rooms. The lower moisture content range (3 to 5% M.C.) should be used for all layers in hot pressing with liquid resins. If the material to be glued is considerably off standard in moisture content, it should be conditioned for several days. This moisture content can often be anticipated and guarded effectually in the veneer preparation departments.

Cold Pressing

In order to avoid confusion, this description will refer only to the use of casein, vegetable and soya-bean glues.

Animal glue is not included, but is little used in plywood operations, and in its use it is advantageous to have work-room temperatures around 90° F., and to keep the glue heated as it is applied. Sometimes the wood parts also are preheated to avoid chilling the glue immediately after its application.

The glue-room technique is essentially the same for vegetable, casein and soya-bean glues, but the preparation of the mixtures for each kind of glue is outlined in Section III, pages 57-61, where the glue characteristics are described and compared.

The use of liquid resin adhesives, under the reaction of chemical reagents, sometimes, but inaccurately, called the cold-pressed resin process, is described later, page 179, and is quite different from the general cold-pressed glue procedure that follows immediately.

Veneer Press Types and Pressure Charts

The earliest type of veneer press was the sandbag, shown in the mural on page 20, and used in ancient Egyptian times. It is believed that bags of heated sand were also used to accelerate the drying of the glue, but the evidence is not very clear. This same technique of pressure from bags of sand is still used in laying linoleum or other floor coverings, to give the cement an opportunity to get its initial grip.

The first form of mechanical press was the hand-operated screw press, which occurs in many forms and types. For larger sheets of plywood three or four screws were arranged in a single frame to go across the plywood, and then these frames were placed every foot or foot and one half along the length of the plywood. Sometimes the screw revolved in the fixed nut and in other cases the nut was turned inside the frame. These hand presses are still

used on large irregular sizes of plywood and in factories where plywood production is a minor item. A formula has been devised for calculating the pressure obtained in a screw press, but only approximate accuracy can be expected from its use.

Another form is the **motor-driven screw press**, where two or four large bolts or screws are anchored in the lower bed of the press, with corresponding sleeve nuts above that raise and lower the top head of the press. This construction may also be inverted, with stationary nuts or threads in the bed, and revolving screws that are turned above the press head. In either case the nuts or screws are connected by gears or sprockets and motor driven. The pressure on the plywood can be computed approximately by the electric current demand.

The **hydraulic press** is almost universally used where plywood is produced in any substantial volume. The piston, or pistons, for moving the lower platen is usually near or below the floor, with a rigid upper head. Specific pressures on the plywood are computed easily and accurately by the following formula:

$$P = \frac{G \times A}{J} \qquad \text{or } G = \frac{J \times P}{A}$$

where P = specific pressure on the plywood area, lb. sq. in.
G = pressure guage (of pump) reading, lb.
A = area of pistons or piston of press, sq. in.
J = area of the plywood, sq. in., or width x length of plywood.

Every hydraulic press should have its pressure schedule posted at a convenient location for frequent reference to secure proper pump

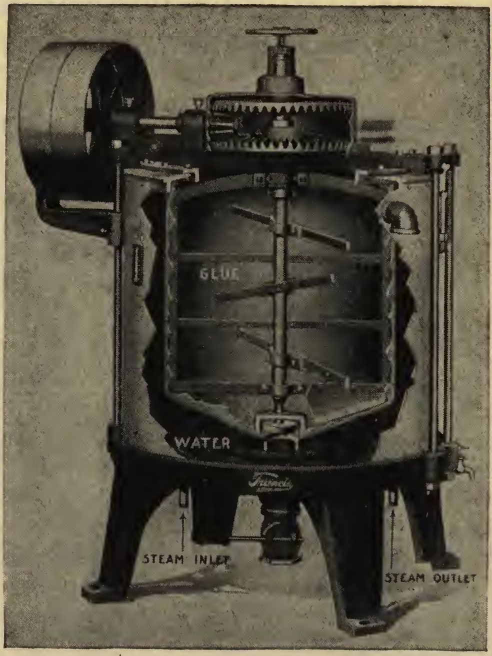
Table VI. 1
Required Hydraulic Pump Pressures

100 lb. sq. in. on plywood
Total piston area, 50 sq. in.

Lengths of Plywood	*Widths of Plywood*					
	12″	18″	24″	30″	36″	*Etc.*
12″	288	432	576	720	864	
18″	432	648	864	1080	1296	
24″	576	864	1152	1440	1728	
30″	720	1080	1440	1800	2160	
36″	864	1296	1728	2160	2592	
42″	1008	1512	2016	2520	3024	
48″	1152	1728	2304	2880	3456	
54″	1296	1944	2592	3240	3888	
60″	1440	2160	2880	3600	4320	
Etc.	Etc.	Etc.	Etc.	Etc.	Etc.	Etc.

pressure and insure uniform gluing pressures on different sizes of plywood. Normal pressures used for gluing plywood by these adhesives are 75 to 100 pounds per square inch, without reference to the species or density of the wood. A convenient form for such a schedule is given in Table VI. 1.

The above schedule is reduced to simple figures, for easy understanding, assuming a piston area of 50 square inches. In a factory schedule, the plywood size differentials should be 3 inches in each direction, and actual aggregate piston area employed. A brief tabulation of plywood areas and piston sizes is given in the tables on pages 305-7.



Courtesy, Charles E. Francis & Co.

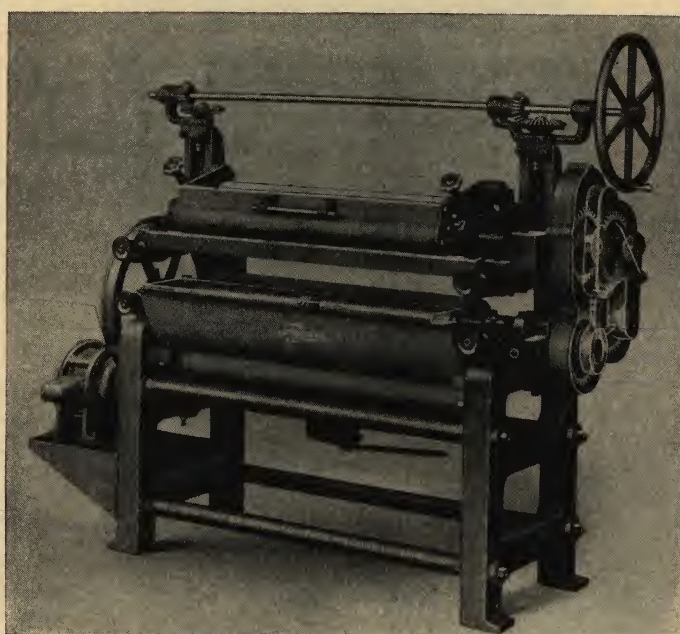
Fig. VI. 15—Glue mixer and cooker, with jacket for steam or water.

Most plywood presses have two pumps, often cross connected, one with large volume for rapid press closing, and the other with small volume for prompt building up of high pressure. Both reciprocating and rotary pumps are used.

Glue Mixers and Spreaders

The preparation of the glue mixtures has been described elsewhere (page 57). The **mixer** for vegetable glue requires a jacket, with steam and water connections, for controlling cooking temperatures. Casein and soya-bean glues are mixed cold. Mixers should be provided with double sets of paddles turning in opposite directions to disperse thoroughly the various ingredients. A standard type is shown in Fig. VI. 15. The shape of the mixer paddles should hug the sides and bottom of the receptacle to prevent accumulation of raw materials. In general, mixer speed for vegetable glue should be 30 r.p.m., and for casein and soya bean 60 r.p.m. up. Mixers should be capable of easy cleaning and outlet pipes and valves should be of liberal size. A desirable addition to standard types of mixers is a sifter, holding 100 pounds, and feeding any powder ingredient slowly to keep lumping at a minimum.

Glue is usually spread simultaneously on both sides of the wood layer, by passing them through between two oppositely revolving glue-carrying rollers. Each **glue-spreading** roller, usually of steel, is provided with a **doctor** bar or roller to regulate



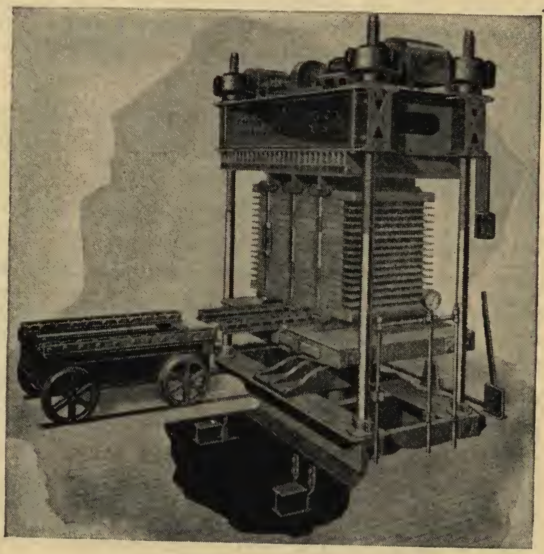
Courtesy, Charles E. Francis & Co.

Fig. VI. 16—Glue spreader, motor driven, with corrugated metal rollers.

the amount of glue applied. Glue rollers are corrugated to permit a better control of the spread factor. Casein glue spreaders have finer corrugations than those for vegetable glue since casein is less viscous. A typical glue spreader is shown in Fig. VI. 16. The lineal speed of the surface of the glue-spreading rollers has much to do with the uniformity and amount of the spread. Different species and rough- or smooth-cut veneer require different spreads; in general dense and smooth-cut veneers require less glue than either rough-cut or porous woods. Variable speed attachments, while now used to only a limited extent, are important adjuncts to the efficiency of proper glue spreading.

Bale Clamping Devices and Storage

These consist essentially of **heavy head blocks**, usually about 4 inches thick, of a plywood type of construction, but made of crossed layers of lumber, together with **"I" beams**, whose ends extend beyond the edges of the head blocks, above and below,



Courtesy, Charles E. Francis & Co.
Fig. VI. 17—Cold hydraulic press, closing from below.
Note clamped bale, ready to remove to roller top truck at left.

and engage **clamp bolts** or rods with right and left nuts, that are tightened while the bundles are still under pressure, as shown in Fig. VI. 17. It is important that a sufficient number of head blocks be available so that they are not much wider than the

plywood, and that the clamps be as close to the edges of the plywood as possible. Plywood cauls, 3-ply, ⅜ inch thick, with waxed surfaces are often used between plywood faces in the bales or bundles, or at least between every three to five layers of thin plywood to preserve flatness and to prevent lapped joints or other defects from injuring the adjacent plywood in the bundle.

Clamped bundles must remain under pressure for a sufficient interval to give the glue its initial set, seldom less than four hours and usually over night. Bundles or bales usually are moved by an overhead conveyor from the press to a bale room where heat is desirable to accelerate the removal of moisture from the edges of the plywood. The hot air from the plywood redriers is often carried by ducts from the redrier to the bale room.

Redriers and Surplus Glue Solvents

It is important that the surplus water from the glue mixture that is introduced into the dry veneers when they are spread with wet glue be removed from the plywood. The importance of this redrying is seldom appreciated, but its magnitude is clearly shown in Table VI. 2.

In order to make both sides of the plywood available for evaporative action, it is customary to pile plywood on successive layers of narrow (¾-inch square) sticks, immediately as it is removed from the clamped bundles. Sticks should be at right angles to the grain of the thickest layers in the plywood, not over 12 to 18 inches apart, and in accurate perpendicular alignment. The top of the load should be well weighted to hold plywood flat during redrying. Plywood that is dried to normal while held flat will seldom develop warping troubles, while on the other hand, plywood that is used with too high or too low a moisture content is very likely to distort in subsequent manufacturing processes, or in the finished product, as it gradually becomes normal.

There should be active air circulation in the redrier, and partial recirculation is often practical and economical. Temperatures may be 110° to 120° F., with relative humidities of 50 to 60%, depending on the amount of moisture to be removed per load of plywood stock, and the time that can be allotted to the redrying operation. Baffles and curtains will often be effective in directing the current of air through the loads of plywood, along the direction of the sticks.

Attention should be called to the fact that, in Table VI. 2, the assumed ratio of glue solids to water is 1:2. This is customary in most low-cost applications. In higher grade work these ratios may

Table VI. 2
Data on Redrying Plywood to Normal Moisture Content of 5%

Based on 1000 Square-Foot Areas

Description	Thickness and Plies						
	1/8″ 3-ply	3/16″ 3-ply	1/4″ 3-ply	5/16″ 5-ply	3/8″ 5-ply	13/16″ 5-ply	7/8″ 7-ply
Weight of wood, poplar at 5% M.C.	275 lb.	412 lb.	550 lb.	687 lb.	825 lb.	1787 lb.	1925 lb.
Number of glue lines	2	2	2	4	4	4	6
Glue mixture and spread basis, 90 lb., 1 part solid and 2 parts water	180 lb.	180 lb.	180 lb.	360 lb.	360 lb.	360 lb.	540 lb.
Glue solvent moisture added in spreading glue	120 lb.	120 lb.	120 lb.	240 lb.	240 lb.	240 lb.	360 lb.
Assuming half of above water evaporates from surfaces and edges, during spreading and while in clamps. Water remaining in plywood is...	60 lb.	60 lb.	60 lb.	120 lb.	120 lb.	120 lb.	180 lb.
Surplus M.C. that must be re-dried to bring plywood to normal 5% M.C. for use..	22%	15%	11%	17%	15%	7%	9%
If surplus M.C. in lumber core assumed to be within 1/4″ of either surface	......	......	......	......	......	11%	......

Weight of dry glue solids not included in these calculations.

be 1:1½ or even 1:1¼, in which case the conclusions of the table would be altered accordingly.

Department Layout

Layouts for plywood departments are largely dependent on adjustments that must be made for size and shape of room, windows, columns, stairways, etc. The accompanying layout, Fig. VI. 18, shows the proper sequence of operations and suggests a convenient grouping of the essential equipment for volume production. Many other arrangements are in successful use. The size of the crew depends on the volume of production and the complexity of the plywood. A stock man is essential to keep all stations supplied with adequate material and avoid any interruptions in machine operation.

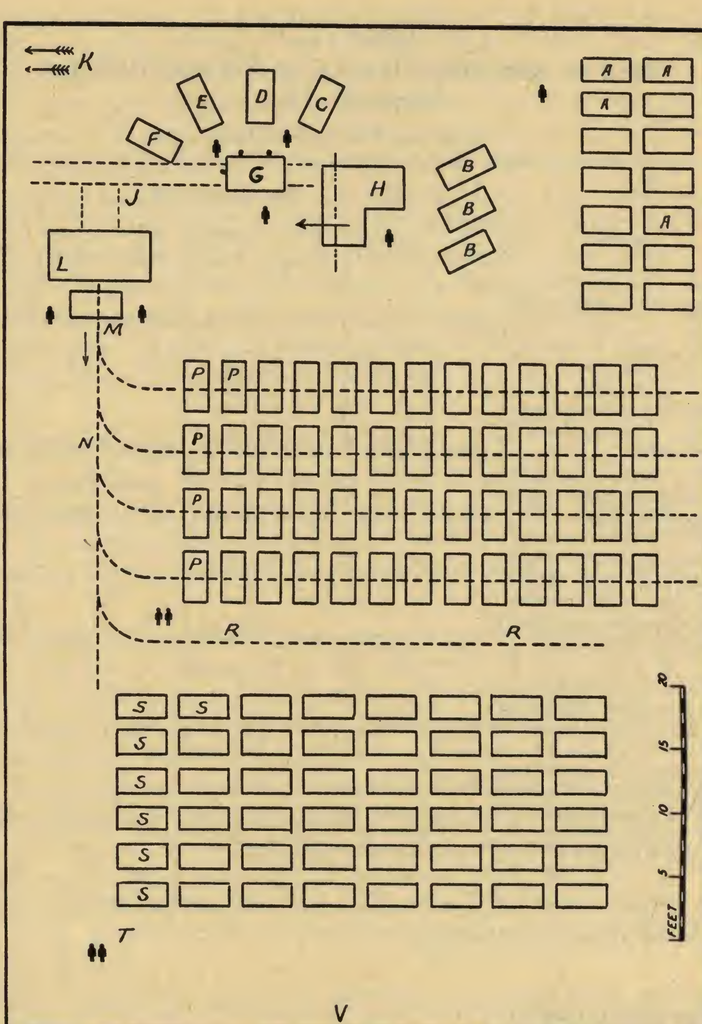


Fig. VI. 18—Layout for glue department, cold pressing.

A—raw material, on factory trucks, just received from air-conditioned storage room. *B*—crossbands for spreader. *C*—veneer backs. *D*—veneer faces. *E*—veneer or lumber cores. *F*—plywood cauls. *G*—lay-up table. *H*—glue spreader. *J*—tracks from spreader to press. *K*—storage room for head blocks, plywood cauls, "I" beams and clamp rods. *L*—cold press. *M*—clamped bale, just out of press. *N*—overhead conveyor from press to bale storage room. *P*—bales in storage. *R*—unclamping and sticking-up for redrying. *S*—stuck plywood on factory trucks in redrier. *T*—unsticking from factory trucks. *V*—plywood on factory trucks ready to dimension.

Hot Pressing

Hot pressing differs in several ways from the cold-pressing operations just described. Some of the important differences are:

1. Hot-pressed plywood is ready for the next factory operation as soon as it is removed from the hot press and cooled.

2. Hot-pressed plywood is well dried in the press and sometimes has to be sprayed or dipped to restore its normal moisture content. Both of these points are in contrast to cold gluing, where the interval between pressing and the subsequent factory process may be a matter of several days, which period is essential to remove the surplus moisture of the glue solvent.

3. Hot pressing requires thinner spreads of the adhesive, as any excess water that cannot readily be absorbed in the wood tends to form steam blisters, under heat, with resulting poor bonds.

4. Hot pressing requires higher pressures, partly because of the thinner spreads, and partly because it is the nature of resin adhesives to polymerize better at as high a pressure as can be used without crushing the wood to excess.

Courtesy, Williams, White & Co.

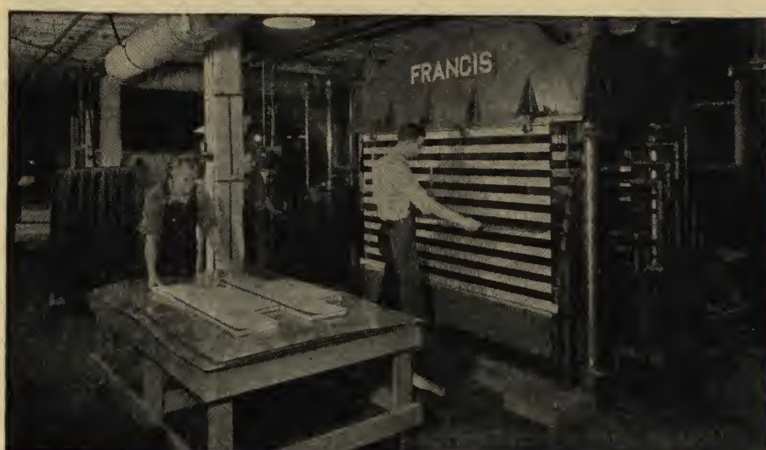
Fig. VI. 19—Ten-opening hot press, ready to load, equipped with combined low-high pressure pump.

In general, hot pressing requires more precision and care than cold pressing. Wood adjusts itself rather slowly to abrupt changes in temperature and moisture, and any quick treatment demands more care than a slow process. The conventional methods of cold gluing have not tended to inspire or inculcate exactness, as the whole operation is an untidy one. Long-established habits toward the liberal use of a low-cost glue, as well as the known tendency of wood to become adjusted gradually to different conditions over the necessary gluing interval, have both tolerated a degree of inefficiency that has, unfortunately, come to be regarded as standard practice.

Since the technique of hot pressing differs between the use of resin films and liquid resins, these two processes will be described separately, immediately following the outline of hot-pressing equipment.

Hot Presses and Accessories

Two actual installations of hot presses are shown. That in Fig. VI. 19 has the combined low-high pressure pumping mechanism at the right in front of the window, just below the gauges; that in



Courtesy, Charles E. Francis & Co.

Fig. VI. 20—Hot press with intensifier equipment, partly loaded with open charge on lay-up table.

Fig. VI. 20 has a low-pressure pump and an intensifier for high pressure at the rear center. In both cases the pistons for closing the press are below, and the bottom platen travels up and down,

while the top head is fixed. The steam plates are about 2 inches thick, resting, when the press is open, on a series of steps, with a "daylight" of 2½ to 3 inches. The steam plates are drilled with an

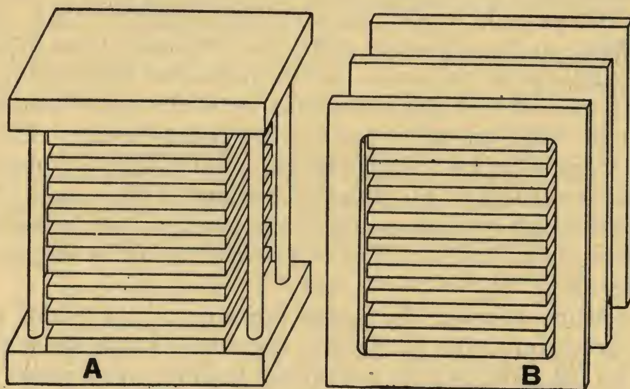


Fig. VI. 21—Diagram of hot-press construction.
A—strain-rod type. *B*—one-piece, steel-frame type.

intersecting series of holes in both directions, plugged with long and short plugs, resulting in continuous labyrinthian passages for the circulation of steam. The steam connections, both supply and drain, may be sliding or angle joints, or flexible metallic hose.

Hot-press designs are of two general types: with **strain rods** to carry the pressure, as in Fig. VI. 21A, in which the top and bottom heads may be of cast iron or built up of structural steel; or a **one-piece steel frame** construction (Fig. VI. 21B) with openings for the heated plates cut in a series of vertical steel frames. Both types are in extensive use, and if properly designed, there is little difference in cost and utility.

Hot presses have been made in many sizes, but experience is demonstrating that the more usual size for furniture work is 60 inches wide by 80 inches long, with ten daylights or openings. For stock panels the favored size is 50 by 100 inches, which will produce 4- by 8-foot panels. Where hot presses have more than 12 openings, it is difficult to load manually, and mechanical loaders are needed.

There are three types of pressure production units that are in common use, the **combination pump**, where the large volume low-pressure portion of the pump, required to close the press quickly, is automatically supplemented by the high-pressure devices that build up the desired pressure after the press is closed. Another method of arriving at the same result is an **intensifier**, with a sim-

ple-pressure pump of approximately 300 pounds maximum pressure. The intensifier itself is a two-ended piston, which, when the large end is under 300-pound pressure, will build up the pressure at the small end (with only one tenth the area of the large end), to the 3000 pounds needed for the high-pressure stage. As this press closes on the plywood, under the impulse of the 300-pound pump, a trip lever throws a differential valve that connects the high-pressure end of the intensifier with the press pistons, and carries the final pressure up to the desired point. The third method consists of two **simple single** pumps, usually rotary, with maximum pressures of the order of 300 and 3000 pounds. The relation of the high-pressure pump to the press pistons is the same as that of the small, high-pressure end of the intensifier described immediately above.

The relation between the gauge pressure of the pump and the specific pressure on the plywood is the same as that given for cold presses on page 152, but the hot presses usually have a series of relatively small, well-distributed pistons, while the cold presses commonly have only one large central piston. In cold pressing it is customary to use a uniform pressure on the work, from 75 to 100 pounds, varying the pump pressure according to the size of the plywood; in hot pressing, resin adhesives require as high a pressure, to cure properly, as the softest layer of wood in the assembly will stand without undue crushing. In order to secure intimate contact between the surfaces of the adjacent layers of wood, slight thickness compression, of the order of 5 to 10%, is often desirable.

Hence the **pressure schedules** used in the operation of hot presses should provide for pressures beginning at 150 pounds for the more porous woods, up to 300 pounds for such dense woods as maple and birch. A convenient form of control schedule is given in Fig. VI. 22, which should be computed for each press and posted near gauge board.

The table is filled out completely by applying the following formula to all areas and specific pressures required.

$$\text{Pump Pressure} = \frac{\text{Plywood Area} \times \text{Specific Pressure}}{\text{Aggregate Area Press Pistons}}$$

Example: With four 8-inch D press cylinders, what pump pressure is required for 150 pounds per square inch on a panel 20 by 62½ inches (1250 square inches)?

$$\text{Pump Pressure} = \frac{1250 \times 150}{4 \times 50.25} = 934$$

PLYWOOD AREA SQ.INCHES	SPECIFIC PRESSURE — POUNDS PER SQUARE INCH						
	150	175	200	225	250	275	300
250							
500							
750							
1000							
1250	934						
1500							
1750							
[illegible]							
[illegible]							
4750							
5000							

All areas in square inches and pressures in pounds per sq. in.

Fig. VI. 22—Hot-press control schedule.

Sheet aluminum cauls serve an important function in hot pressing, but in some types of work, such as large stock panels that completely cover the hot plates, their use is unnecessary. The principal reasons for using them are:

1. To delay slightly heat penetration, and possible precure of the resin, while loading and closing the press.

2. To keep particles of hard resin from marring the surfaces of the hot plates.

3. To prevent rust stains on the steel platens from discoloring light-colored face veneers.

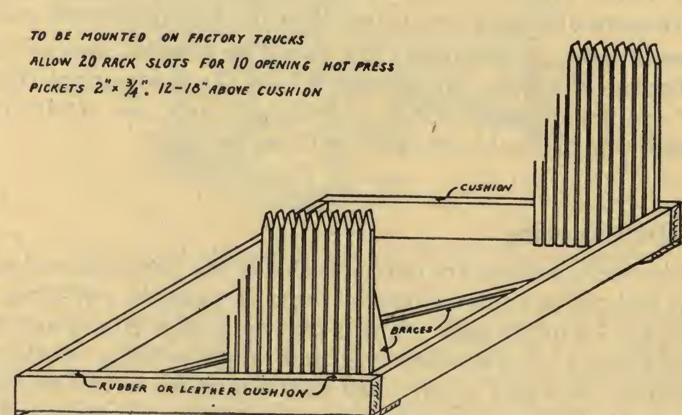


Fig. VI. 23—Caul rack.

4. To simplify the loading or charging operation, when several small sizes of the same thickness are placed in a single-press opening.

These cauls should be approximately two inches wider than the depth of the hot plate to facilitate loading or discharging and prevent hands from coming in contact with the hot metal. They should also

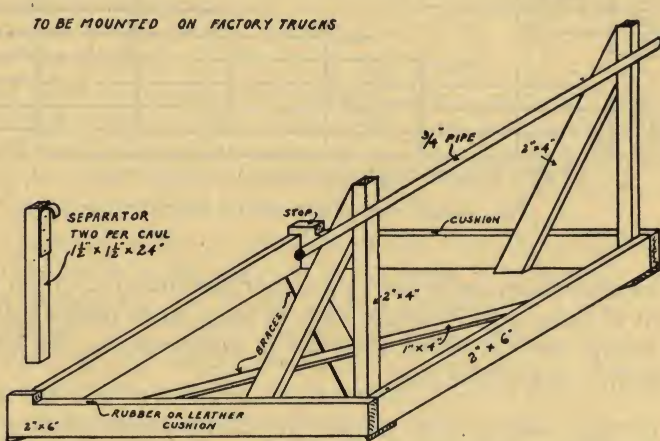


Fig. VI. 24—Caul rack.

be one inch narrower than the hot plate, to avoid catching and bending corners during loading. The preferred grade of aluminum is 16 gauge, stretcher sheets, heat treated, medium soft. Some users prefer harder grades, which are more costly, do not dent so easily, but are more difficult to straighten than the first-mentioned grade.

Several types of caul racks are found serviceable, two of which are illustrated in Figs. VI. 23 and VI. 24. It is important that the racks are well cushioned, so that if hot cauls are inadvertently dropped into the rack, the edges will not be bent.

Film Dimensioning

Resin-film adhesives are only available in the phenol-formaldehyde group, and the best known type is Tego. It comes in roll form, usually 50 and 74 inches wide. There are two grades, Nos. 1 and 2, the former being a general utility type, and the latter being odorless and somewhat more rapid in cure, and requiring more careful technique. Both weigh 12½ pounds per 1000 square feet, and both full and partly used rolls should be stored on end and protected from mois-

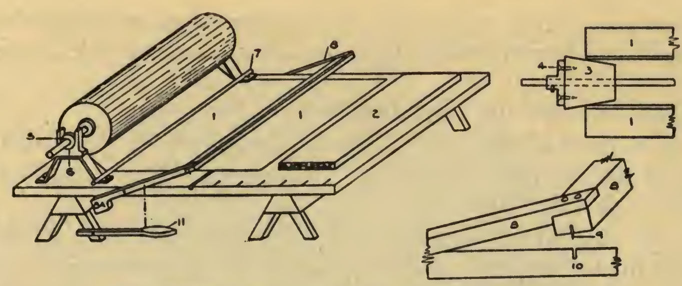


Fig. VI. 25—Homemade film-cutting machine.

1—roll of resin film. 2—pile of cut film. 3—tapered wooden plug. 4—metal flange with set screw. 5—removable roller bearing. 6—open bearing support. 7—guide rod. 8—knife bracket. 8*A*—counterweight. 9—knife. 10—knife slot. 11—operating foot lever.

ture and heat. Under favorable conditions its storage life is one year, but it is desirable not to purchase over three months' requirements.

Small consumers can build a simple cutting machine as shown in Fig. VI. 25, while a larger machine for cutting two rolls at once is

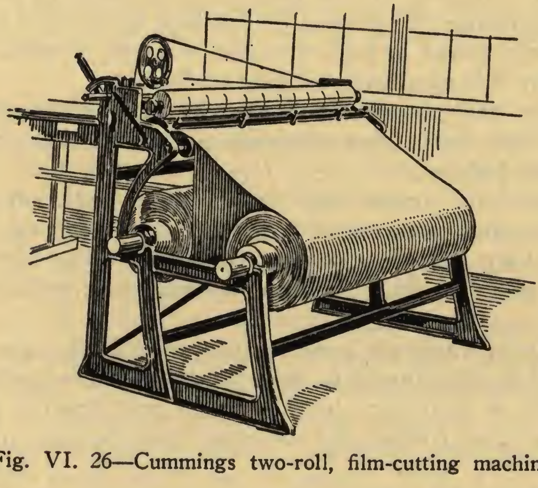


Fig. VI. 26—Cummings two-roll, film-cutting machine.

commercially available for large film users, and is illustrated in Fig. VI. 26. Film should not be cut more than a day ahead of requirements, and should be kept clean, as well as protected from pressure, heat and dampness. It should not be piled over 2 inches high, as the weight of higher piles might cause the sheets to adhere

together on a warm, moist day. The hollow cores on which the film is wound and stored usually have an inside diameter of 5 inches.

Moisture Content for Film Bonding

It is a general rule that all veneer layers to be assembled into plywood should have a moisture content of 5% or less, and this applies to liquid resins.

In the case of the use of resin film, it is necessary to have a slightly higher moisture content, to provide an initial flow for the resin of the film, just when the heat and pressure are applied. It is the normal cycle of the thermosetting resins to soften slightly at the first application of heat, and then to harden irreversibly, i.e., further heat will not soften them again. A little moisture in the wood, at the instant of softening under heat, helps to develop the proper mechanical adhesion.

Standard 5-ply constructions, if the veneers (1/16 to 1/20 inch) are to be used for plain unfigured plywood, require all layers to contain 7 to 9% M.C. If, on the other hand, the veneer faces are figured or delicate, they should be kept at 5% or less, and the crossbanding conditioned to 8 to 12% M.C. The reason for keeping the faces so dry is to prevent face checks under combined pressure and heat. The presence of moisture on one side of the film is adequate. Lumber cores should be kept at a low moisture content, as excess moisture here will encourage warping under heat.

In the case of 3-ply constructions, with figured faces, the veneer or lumber core should have adequate moisture for the initial resin flow mentioned above.

The thinner the veneer that carries this surplus moisture, the higher its required percentage: 8 to 12% for crossbands applied to 1/20 inch; very thin (1/40-inch) reinforcing backs for 2-ply may require up to 16%; thick veneer cores will work well at 6 to 8% M.C.

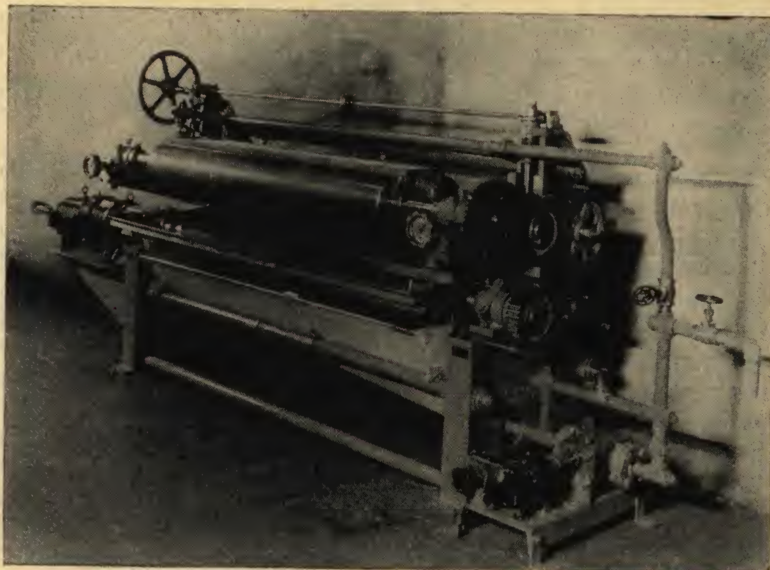
In the case of multi-ply constructions, over 5-ply, every alternate layer should be conditioned to serve as the moisture carrier.

Experience is necessary to understand and provide the proper optimum moisture content for the many constructions used in film bonding.

Too much moisture will result in a weak bond, and may be the cause of steam blisters in the hot press.

Resin Mixers and Spreaders

The type of mixers required for resin adhesives is quite similar to those used in mixing conventional cold glues. Resin adhesives, how-



Courtesy, Charles E. Francis & Co.

Fig. VI. 27—Spreader for resin adhesives, with rubber rollers.
Note recirculating, motor-driven, rotary pump at right, with pipe connections plugged for easy cleaning. Lower pan serves as reservoir for liquid adhesive.

ever, are considerably heavier, and it is important that the blade or paddles be equipped with bars or scrapers that hug the bottom and sides of the receptable as closely as possible, so that there is no opportunity for the accumulation of unmixed or partly mixed material. Mixers may have either horizontal or vertical shafts, those equipped horizontally, like bread mixers, having some advantages in mixing resins that are substantially extended with flour. The ingredients for resin adhesive mixtures are outlined on pages 63-7.

Mixers are usually piped direct to spreaders, but pipe connections should be provided with plugs for easy mechanical cleaning.

Spreaders for resins are equipped with corrugated rubber-covered rollers, to permit very thin spreads. Calibrated dials on the doctor rolls are useful in the regulation of spreads. These doctor rolls, for controlling the amount of adhesive on the spreading rolls, are of metal and should be chromium plated. It is advisable to have a recirculating rotary pump on a resin spreader, using the lower tank as a storage reservoir, and pumping up merely enough to supply the rolls, all as shown on Fig. VI. 27. These pipe connections, like those on the mixer above, should be arranged for easy cleaning. Many

operators make complete piping connections, with proper valving, between the mixer and spreader.

All mixing and spreading equipment should be kept scrupulously clean, and should be washed with cold water at least once every 24 hours.

The amount of glue spread should be only enough to cover the material and remain on the surface until pressing. Urea resins require prompt pressing, while phenolic resins do not. This thin spread is in direct contrast with the heavy spread required in cold pressing, where the volume spread must be adequate to have glue on the joint line when it hardens, in spite of the substantial absorption into the wood during the hours of setting. More liberal resin spreads are needed on soft porous woods, like spruce and basswood, whereas much thinner spreads may be adequate on maple and birch. Loose-cut and rough veneer also requires more adhesive than smooth, tight-cut stock. A fair average for a smooth-cut dense wood, like maple, is 25 to 30 pounds liquid mixture per 1000 square feet of single line, and a maximum for porous and rough-cut veneer should not exceed 35 to 40 pounds.

A convenient method of testing spreads is to prepare veneer samples one foot square of the same lot of material that is going through the regular run on the spreader. The sample should be weighed in grams and marked; run through the spreader for a total of adhesive spread of 2 square feet, on both sides; reweighed and marked again. The first weight is subtracted from the second to give the net weight of the adhesive that has been spread on a representative piece. Then the following formula is solved:

$$S = \frac{W \times 500}{453.6} = 1.102\,W$$

where

W = weight added by adhesive, in grams, on 2 square feet.
S = spread in pounds of liquid mixture per 1000 square feet.
453.6 = conversion factor, grams per pound (avdp.).

An easy rule, that is sufficiently accurate, is to add 10% to the net **grams** per 2 square feet to obtain **pounds** per 1000 square feet. An exact conversion is given in Table VI. 3.

The test may also be made on a weighing scale reading in ounces (avdp.) (W^1) and decimals thereof, in which case the formula becomes:

$$S = \frac{W^1 \times 500}{16} = 31.25\,W^1$$

Table VI. 3
Conversion of Liquid Adhesive Spread, Grams on 2 Sq. Ft. to Pounds per 1000 Sq. Ft.

Grams 2 *sq. ft.*	*Pounds* 1000 *sq. ft.*	*Grams* 2 *sq. ft.*	*Pounds* 1000 *sq. ft.*	*Grams* 2 *sq. ft.*	*Pounds* 1000 *sq. ft.*
20	22.0	30	33.1	40	44.1
21	23.1	31	34.2	41	45.2
22	24.2	32	35.3	42	46.3
23	25.4	33	36.4	43	47.4
24	26.5	34	37.5	44	48.5
25	27.6	35	38.6	45	49.6
26	28.7	36	39.7	46	50.7
27	29.8	37	40.8	47	51.8
28	30.9	38	41.9	48	52.9
29	32.0	39	43.0	49	54.0

Hot-press Operation

The next step, after the resin film has been dimensioned, or the veneer has been spread with the liquid resin, is the lay-up, which consists in assembling the layers of veneer and/or lumber with the adhesive.

In the case of **urea liquid resins**, this assembly and insertion in the hot press should be as prompt as possible, not over 15 to 30 minutes. In any event the adhesive should still be **tacky** to the

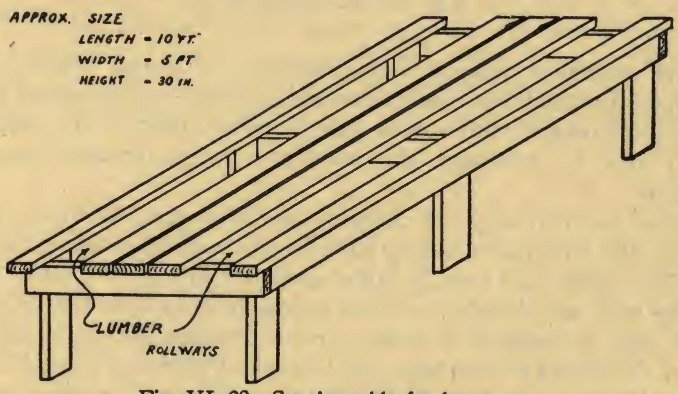


Fig. VI. 28—Service table for hot press.

touch as it enters the press. This lay-up is usually on a roller top table, as suggested in Fig. VI. 28, to facilitate moving piles around without disturbing the relative position of the layers.

With a **phenolic-resin film** the lay-up and assembly can be done at any convenient time, as the interval between assembly and pressing is not important.

With a **liquid phenolic resin** it is preferable to allow an hour between spreading and pressing, to permit the solvents from the adhesive to evaporate, and two or three days will do no harm. The controlling factor is the total amount of moisture in the assembly, i.e., adding together the moisture content in layers before spreading and the surplus from the solvent. If this is more than 15% of the dry weight of the wood, there is danger of steam blisters in hot pressing. Obviously, the hazard is greater in thin assemblies with many adhesive lines, such as ⅛-inch 3-ply or ¼-inch 5-ply.

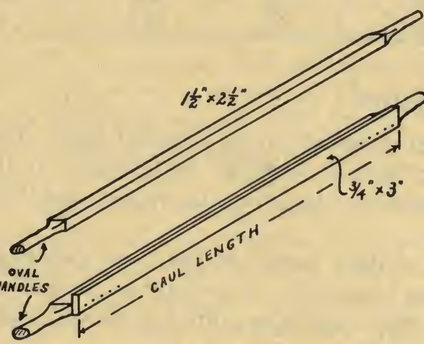


Fig. VI. 29—Lifting bars.

The assembled veneers and adhesives are placed between pairs of aluminum cauls, as many assemblies of the same thickness as can be accommodated within each pair, keeping track of the total plywood area to determine the necessary gauge pressure from the schedule.

There are two ways of charging the hot press. The first way is with a pair of wooden lifting bars (with rounded oval handles, Fig. VI. 29) under each pair of cauls, as shown in Fig. VI. 30A. These lifting bars are dropped as each assembly goes into the hot press. This type of support is to be preferred when the cauls are wide (over 50 inches), or where the individual plywood assemblies are so small that it requires two lifting bars to prevent crosswise sagging in the short trip from the pile to the press. Lengthwise sagging is prevented by the lifting bars as shown in Fig. VI. 30A.

The second way to charge the hot press is to use a single lifting bar, usually of ¾-inch electric conduit (of metal) with ends taped

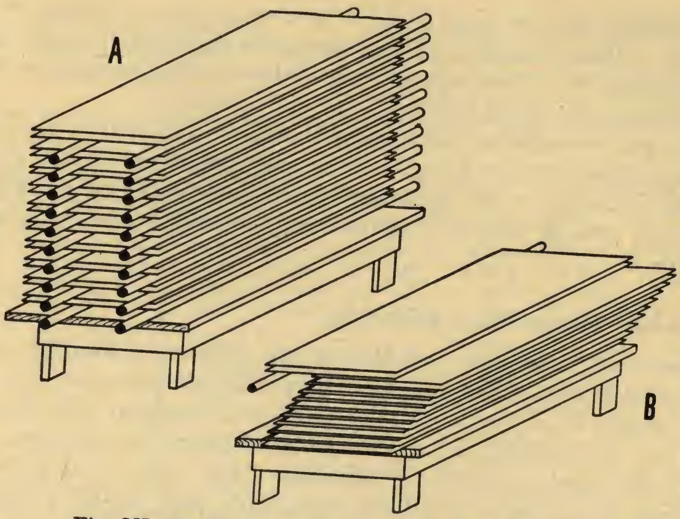


Fig. VI. 30—Hot-press load, ready to charge press.
A—double, wooden lifting bars. *B*—single, metal lifting bar.

to make non-skid grips. The cauls containing plywood assemblies are offset, pair by pair, away from the hot press, each with approximately a 2-inch overhang beyond its neighbor next below, as shown in Fig. VI. 30B. The top pair is left with a 12-inch overhang toward the hot press with lifting rod below it. Each man of the loading crew holds this bar in one hand and with the other grips the pair of cauls (on far side from the press). When this top pair is loaded in the press the next top pair of cauls is pulled forward, supported by the lifting bar, and so on. This single lifting bar is kept

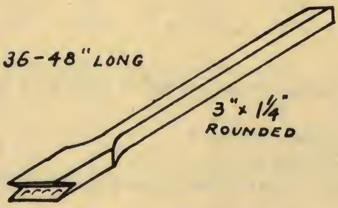


Fig. VI. 31—Pusher bar.

in hand until the entire charge is in the press. This single bar method is quicker and simpler for medium-size hot presses, or where the plywood assemblies are large enough to reach across the cauls, so that the hazard of crosswise sagging is unimportant.

The discharge from the press is by a pusher bar as shown in Fig. VI. 31. Often the pairs of cauls are only pushed out about half a foot, leaving the unloading crew to pull them out in the order in which new charges are to be inserted.

The pressure-control mechanism should be adjusted to arrest the gauge pressure on the pumps at the point indicated for the desired specific pressure on the plywood, according to its initial density and the final density required, considering the allowable compression factors.

Time and Temperature Schedules

Time and temperature conditions are given in Table VI. 4, and high quality bonds will result from careful adherence to the conditions shown in the table. These tables are developed and standardized for the products of the Resinous Products & Chemical Company, and used with their permission. Most other resin adhesives conform to the same standards, but every user should consult his supplier for definite instructions on the product in use.

Time and temperature limits are, in general, liberal, but variations in initial temperature and moisture content of the wood may alter these requirements. It is always advisable to verify them frequently by careful operative tests. Longer time and higher temperatures result in better durability, but may slightly increase the tendency to warp.

Pressures required for hot pressing should be enough to bring the surfaces of the wood into intimate contact, from about 125 lb. per square inch for basswood to 250-300 lb. per square inch for maple and birch, as noted on page 162.

Measurement of "Depth to Farthest Bonding Line" in Table VI 4, on opposite page to be understood as follows

With single assembly in each press opening

- 3-ply—Whichever is thicker, face or back
- 5-ply—Combined thickness of face and face crossing or back and back crossing, whichever is thicker
- 7-ply—Combined thickness of the three outer layers, either side of the core, whichever is thicker

With double assembly of panels in each press opening

- 3-ply—Back to back, combined thickness of face and core
- 5-ply—Back to back, combined thickness of face, both crossings and core

Table VI. 4
Time and Temperature (°F.) Schedules for Hot-pressed Resin Plywood Using 16 ga. Aluminum Cauls

Liquid Urea Resin Mixtures

Core Thickness →		Minutes under Full Pressure					
		1/8″ Core		1/4″ Core		1/2″ Core	
Plate Temperature, °F.		230°	260°	230°	260°	230°	260°
Depth to farthest bonding line	1/16″	3–6	3–5	5–9	4–6	6–10	4–7
	1/28″ & 1/20″	4–8	4–6	6–10	4–7	7–11	5–8
	1/8″	5–9	4–7	7–12	5–9	7–13	6–10
	3/16″	6–11	5–9	8–13	6–11	8–14	7–12
	1/4″	7–12	6–10	9–15	7–12	9–16	8–13
	5/16″	8–13	7–11	10–17	8–13	10–18	9–14
	3/8″	.....	9–12	.....	10–14	.....	.....
	7/16″	.....	11–13	.....	12–15	.....	.....
	1/2″	.....	12–14	.....	13–16	.....	.....

The first figure in each pair indicates time for mixture with equal weights of dry resin and extender and the second where ratio dry resin to extender is 1:3, with other mixtures intermediate. (See page 66.) Higher temperatures are distinctly preferable for the higher flour mixtures, for both bonding speed and durability.

Phenolic Resin Film and Liquid Mixtures

Core Thickness →			Minutes under Full Pressure								
			1/8″ Core			1/4″ Core			1/2″ Core		
Plate Temperature, °F.			280°	300°	320°	280°	300°	320°	280°	300°	320°
Depth to Farthest Bonding Line	Tego No. 1	1/28″	7	5	3	8	6	4	9	8	6
		1/20″	7½	5½	3½	8½	6½	4½	9½	8½	6½
		1/16″	8	6	4	9	7	5	10	9	7
		1/28 & 1/20″	9	7	5	10	8	5½	11	10	8
		1/8″	10	8	6	11	9	7	12½	11	9
		3/16″	12	10½	7½	13½	11½	8½	15	13½	10½
		1/4″	15	13	10	16	14	11	18	16	13
		5/16″	....	17	13½	....	18	14½	....	20	16½
		3/8″	....	21	18	....	22	19	....	24	21
	Tego No. 2 and Liquid	1/28″	5	3	3	5½	3½	3	7	5½	4½
		1/20″	5½	3½	3	6	4	3½	7½	6	5
		1/16″	6	4	3½	6½	4½	4	8	6½	5½
		1/28 & 1/20″	7	5	4	7½	5	4½	9	7½	6
		1/8″	8	6	5	8½	6½	5½	10	8½	7½
		3/16″	10½	7½	6	11	8½	7	12	11	9½
		1/4″	13	10	8	13½	11	9	15	13½	12
		5/16″	....	13½	11	....	15	12	....	17½	16
		3/8″	....	18	15	....	19	16	....	22	20

See footnote on opposite page.

Reconditioning Hot-pressed Plywood

Hot plywood, immediately after removal from the hot press, cools rapidly, and dries out as it gives off heat. Hence there is a tendency for hot-pressed plywood to be unusually dry, a condition that makes the wood brash and brittle and encourages warping. This factor is more conspicuous in film-bonded plywood than in that made with a liquid resin, where the solvent water is introduced into the veneer layers.

It is important that proper steps be taken to restore the normal moisture content of the plywood and to hold it flat during this

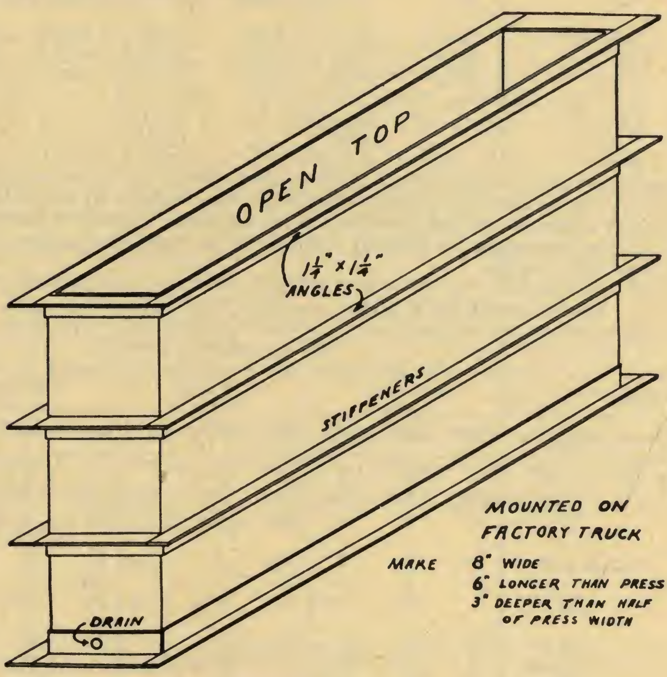


Fig. VI. 32—Galvanized dipping tank for plywood.

normalizing process. There are several ways of doing this. In film-bonded plywood many prefer to dip the hot plywood in water quickly, and lay it up on stickers, properly weighted to hold it flat. A satisfactory form of dipping tank is shown in Fig. VI. 32, and can be mounted on a factory truck. Such dipped plywood will steam freely, but will usually dry to normalcy over night. Some find it advisable to strip off the gummed-paper tape right after dipping, and allow the depression (caused by the tape in hot pressing) largely

to recover. An alternate method is to spray the hot plywood. Some authorities prefer to pile solid, without stickers, after dipping or spraying, thus requiring a somewhat longer period for drying and cooling. Occasionally, it is found desirable to place trucks of plywood on stickers in a fan room, without heat. This will cool the stock in 2 to 4 hours, and is particularly advantageous in cedar-chest construction, where the 2-ply is inadequately balanced and should be built into chests or cabinets promptly.

Under all circumstances the hot plywood should be piled on a solid base, like a heavy head block, with all edges in vertical alignment, and well weighted down. This should be done, with or without stickers, and maintained until plywood is cool and normal. Such a procedure is suggested in Fig. VI. 33.

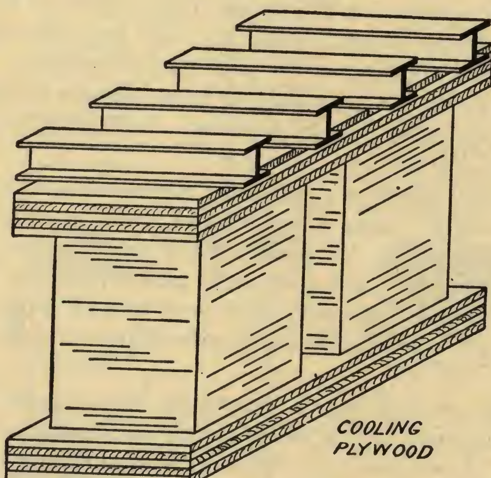


Fig. VI. 33—Plywood normalizing under weights.

In the case of plywood hot bonded with a liquid urea resin, many of the same requirements should be observed. However, this plywood is not so dry as in the case of film bonding, and should not be dipped, since urea resins of certain types and mixtures may be weakened by hot water. It may be sprayed or sponged sparingly if desired, and the tape stripped off. It may be piled solid or with stickers, depending on time requirements. It is highly important to hold this type of plywood flat under weights until cooled.

Carelessness in properly stacking and holding any hot-pressed plywood flat until it cools and becomes normal is a distinct invitation to warping.

There are instances in plywood manufacturing operations where straight-line production methods would favor dimensioning plywood immediately on its removal from the hot press, and before its moisture content has become normal. This can be done at some sacrifice in the smoothness of the saw cuts, since the face veneers of the hot plywood are brash and will chip or sliver in sawing. It is important, therefore, after sawing hot plywood that it be promptly piled, weighted and allowed to temper to normal, all as described above. It is not considered good practice to dip dimensioned plywood, as there may be too much edge penetration of moisture.

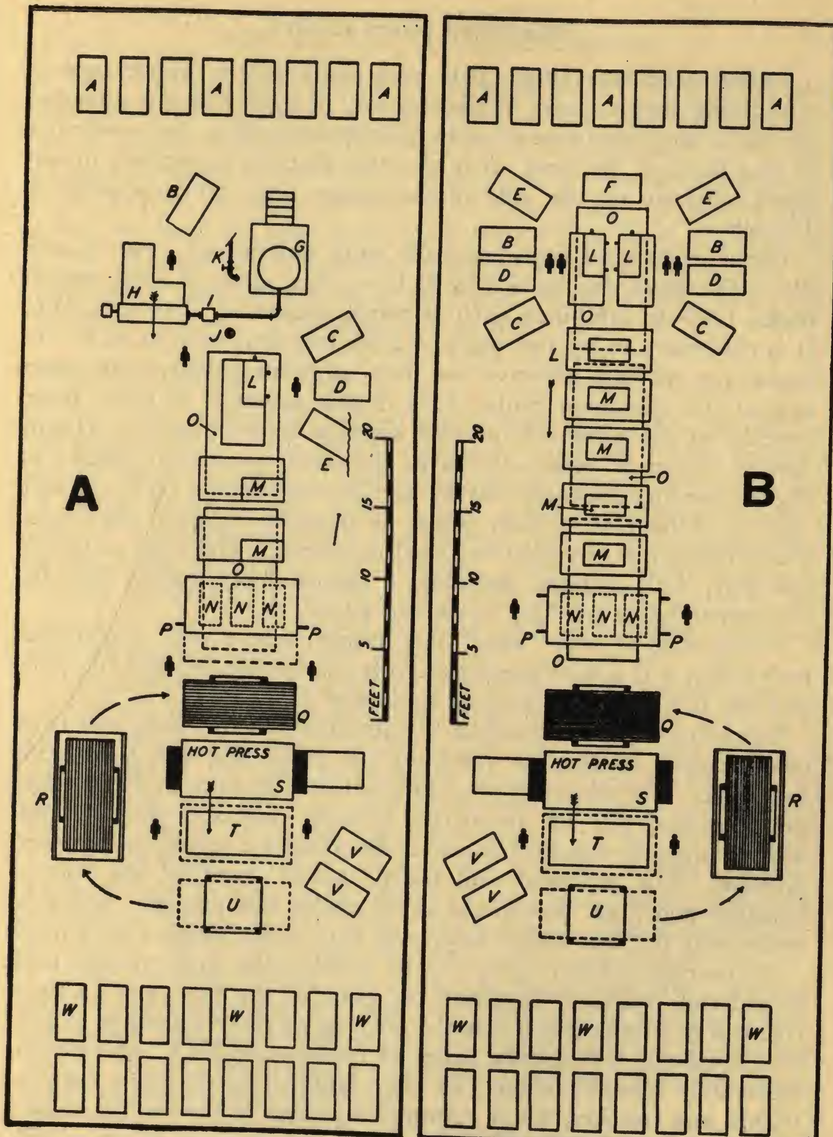
Department Layouts

The distinguishing feature in a hot-press layout is adequate room in front of the press for the proper preparation of the charges or loads of assembled veneers, ready to press into plywood. If space permits, roller-top tables in 10-foot sections provide a convenient way to move forward the succeeding press charges through the various stages that occur before pressing. Such a roller-top table is shown in Fig. VI. 28.

Another convenience is a fan drier for aluminum cauls, to facilitate rapid cooling. Cauls must be cool when used, to prevent the possibility of precuring the resin. While such fans may be located in various ways, the most convenient plan is to have the fan duct below the floor, discharging upward, so that caul racks can be rolled over it en route from the discharge side of the hot press to the loading side.

Three sets of cauls are a minimum requirement, and in cool weather or climates, with a bonding cycle of 12 minutes upward, this number may be adequate. For hot weather and shorter cycles, four or five sets may be found necessary. A set of cauls consists of two for each hot-press opening, and each rack should hold a full set.

The hot-press department layouts shown in Fig. VI. 34 have been found very satisfactory. That on the left (large A) is for liquid resins, and on the right (large B) for film resins. All necessary workmen, except the department foreman, are indicated at their stations. For small work, where a number of pieces of plywood go within each pair of cauls, a larger crew may be needed, or operations will be slowed down.



Courtesy, Furniture Manufacturer

Fig. VI. 34—Hot-press layouts.

A—raw material. *B*—crossbands. *C*—faces. *D*—backs. *E*—cores. *F*—dimensioned Tego film. *G*—mixer on platform. *H*—spreader. *I*—recirculating pump. *J*—floor drain. *K*—water supply. *L*—lay-up station on plywood trays. *M*—assembled with adhesive on plywood trays. *N*—charge in aluminum cauls. *O*—rollway top tables. *P*—lifting bars, two types. *Q*—aluminum cauls in rack. *R*—cauls over cooling fan. *S*—hot press and pumps. *T*—unloading table. *U*—rack to receive hot cauls. *V*—finished plywood, hot. *W*—finished plywood cooling.

Reinforced Faces (2-ply)

Earlier reference (page 141) was made to the importance of reinforcing fragile faces. While this may be done with any adhesive, the use of any liquid glue or resin is likely to result in the penetration of glue through the faces. It is also true that the application of any liquid adhesive on one side of the veneer only, while possible, is difficult.

Hence, reinforced faces are made more satisfactorily with a resin film. The faces should be 5% M.C. or less, while the thin veneer backs, 1/40- to 1/60-inch birch or maple, should be 12 to 15% M.C. It is customary to lay two pairs of 2-ply together, back to back (the backs are without adhesive on their adjacent sides), with faces against the aluminum cauls. This double assembly is often taped together at the corners to prevent slippage before pressing. Highly figured veneer is often uneven in thickness, or several species of slightly varying thickness may be used in combination faces; in such cases a cushion of ⅛-inch poplar is desirable between the backs. This cushion can be cooled and used repeatedly. This type of double assembly, with cushion, resembles a normal 5-ply, except that the two center joints are "dry" (without adhesive).

In the case of very "endy" face veneer, where resin penetration may occur, it is a wise precaution to lay waxpaper between the cauls and the face veneer to prevent unwanted adhesion.

Since any 2-ply construction is unbalanced, it will warp and twist conspicuously on removal from the hot press, and will be difficult to handle. The preferred procedure is to dip at once in water, strip the tape, and pile up alternately between unwaxed plywood caul boards, properly weighted down, as described for regular hot-pressed plywood. The unwaxed caul boards absorb most of the surplus moisture and heat. Reinforced 2-ply, under this process, should be moderately flat, but should always be kept under weights until used.

Authorities are not agreed as to whether the grain of the back should run "with" or "against" the grain of the face, and no fixed rule can be given. Since it is the purpose of the reinforcing to prevent breakage, it is usually better to crosslay the back, especially in moderately figured veneer. In very highly figured faces, such as stumps and crotches, where rupture may occur in the length, parallel grain is often the better procedure. There are cases where a back may be laid at a 45° angle, particularly where the 2-ply is to be used on curved parts.

Resin Bonding without Hot Presses

The normal polymerization of resins is under simultaneous heat and pressure, but there are many types of veneer-to-wood and plywood joints where the application of heat is impractical and sometimes impossible. Methods and reagents have been developed, however, to take the place of this heat reaction, and to convert resin adhesives from the raw to the cured state where hot pressing is out of the question. At the present time such chemical reactions do not produce so complete a bond as does heat. It is not quite so durable or water resistant, nor is it so low in cost.

Typical Example

A typical example of such a requirement is a "swell" or circular plywood front construction for drawers or buffet doors, where a lumber core is desired. If such an item were made in large quantities, it would be possible to design a pair of curved dies, and devise a suitable all-veneer, multi-ply construction for use in the regular hot press. (See Fig. II. 10.) However, a large proportion of such curved shapes in plywood are required in small lots of 50 to 200 sets, and successive designs, to meet style improvements, usually demand changes that would render the preceding dies useless.

The customary procedure is to build up a solid laminated lumber-core block, from standard lumber, glued edge to edge and face to face. This is band sawn to the required curvature and thickness. The width of the saw kerf should be approximately that of the thickness of the sheets of veneer to be placed in the cut. This is shown in the upper half of Fig. VI. 35.

The crossbands can then be spread with the desired resin adhesives, as in the case of normal flat plywood, and the successive layers are nested one on top of the other. These layers, somewhat separated for clarity, are shown in the lower half of the same figure.

If such a block were a cube, two feet in each direction, it would be obviously impossible to apply the usual type of surface heating and expect the heat to penetrate the block sufficiently, in a reasonable time, to cure the joints near the center of the block, or without excessively overdrying the outer layers.

Method of Assembly

Demands of this nature forced the development of a chemical-reactive resin adhesive, to be used without hot presses, and therefore, by contrast and rather unfortunately, called cold pressing, since many leading furniture manufacturers were unwilling to use other

than resin bonds in any part of their products. All-resin bonds encouraged the promotion and advertising of all-weather- and all-climate-proof furniture. The resulting urea resin adhesive required

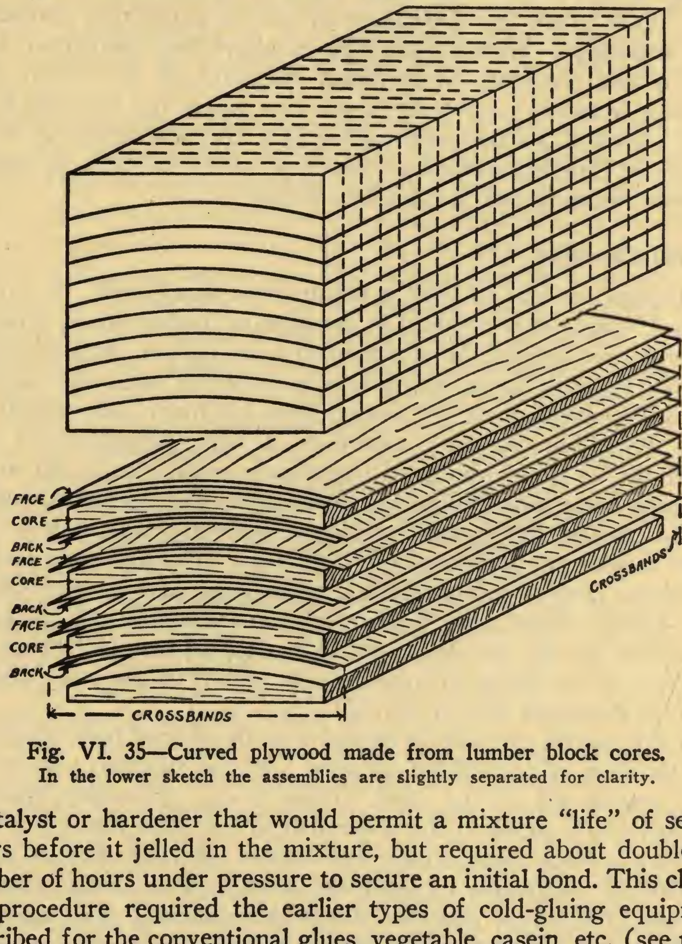


Fig. VI. 35—Curved plywood made from lumber block cores.
In the lower sketch the assemblies are slightly separated for clarity.

a catalyst or hardener that would permit a mixture "life" of several hours before it jelled in the mixture, but required about double this number of hours under pressure to secure an initial bond. This clamping procedure required the earlier types of cold-gluing equipment, described for the conventional glues, vegetable, casein, etc. (see pages 155-6), and the resulting bond approached the quality and durability of the resins. The mixing and spreading of this non-heat-curing resin did, however, require the same kind of equipment as used for liquid phenolic and urea resin adhesives, as described on pages 166-7.

It should also be noted that the conventional cold presses were, in general, designed to exert specific pressure of 75 to 100 pounds per square inch on the plywood, while resin bonding required approximately double these pressures. As a consequence, for resin bonding,

the use of presses intended for cold pressing involved some problems of adequate pressure that required careful attention.

If such clamped blocks of curved plywood can be placed in a kiln at 125° to 150°F., the minimum clamping time can be shortened substantially. In other words, heat is always a desirable factor in curing resin bonds. It is also true that such cold-setting resins cannot be used satisfactorily at temperatures below 75°F.

Plywood without Hot Presses

While hot pressing is preferable for flat plywood, or for such shapes as can be made in pairs of heated dies, there is often a point at which volume requirements will not justify the outlay required for the installation of hot-press equipment. In such cases these chemical-reactive catalysts may be used successfully, although at some sacrifice in cost and durability. The technique is essentially the same as described above for curved constructions.

Clamped bundles of this type of resin-bonded plywood are customarily placed in a kiln, at 125° to 150°F., over night before unclamping. They should never be allowed to remain in temperatures below 75°F.

It should be noted that the over-dryness of hot-pressed plywood does not occur, but a surplus of moisture from the glue solvent may be found in thin constructions, where resin bonding without hot presses is employed. This may require the same type of redrying, as outlined on page 156 for the conventional cold-setting glues.

If extra large plywood is required, beyond the capacity of the hot press, this cold-bonding process may be employed with large hand-operated clamps.

It is important that all plywood, by the cold as well as by the hot resin process, be kept flat and under weights, until it has become normal as to moisture content and temperature.

Aging Requirements

In the hot-press operation, the resin can be polymerized to the desired extent in the hot press, and little further strength increment is to be anticipated thereafter. However, the wood may be quite brash, as it comes from the hot press, and should be allowed to become normal as to moisture content and temperature before the full strength of the wood-adhesive combination can be realized.

The situation in cold bonding is quite different. The polymerization under the influence of a chemical reagent is much slower, and while the initial adhesive grip must occur before the release of pres-

sure, it usually requires several days to develop the full strength of the bond. The initial grip is, in most cases, sufficient to permit the subsequent machining of the wood and plywood parts, so that ordinarily this gradual strength increment does not cause any factory delays.

A somewhat similar situation may occur in certain types of hot pressing, where the heat and pressure are continued long enough to secure an initial grip, and the completion of the cure is obtained by placing the plywood in an oven. In some instances the hot plywood, solid piled, is allowed to stand where the initial heat will be retained as long as possible, and carry forward the process of polymerization.

Assembly Adhesives

While not wholly a plywood problem, there are many joints between wood and wood or wood and plywood, where it is desirable to employ a non-heat-reactive resin adhesive, such as cabinet joints in furniture and interior trim, construction joints in boats and aircraft, school and home-shop work, and the like. In most of such cases the so-called cold-setting resins are applicable. The richer mixes are preferable, since the adhesive costs are relatively unimportant. The mixes usually should be as thick as can be spread with a brush, to prevent soaking away from the glue line during the relatively slow process of cure. Sometimes a precoating of a more dilute resin mixture will keep a larger amount of the resin on the joint. It is often desirable to spread both surfaces. In putting together woods of unlike density, it is sometimes desirable to pre-coat only the more porous wood. Pre-coating helps on angling or scarfed joints. Pressure may be obtained in many ways: clamps, nails, screws, bolts, staples, straps, tape, etc. Adequate pressure and intimate contact of the surfaces are essential.

All such joints are benefited by moderate heat, and several days are required for the development of the full strength of the bond. Pressure, however, can usually be released in a few hours.

The large variety of resin adhesives offered for this type of work makes it desirable to consult the supplier for specific methods of preferred usage.

ELECTROSTATIC HEAT FOR RESIN BONDING

The method so far described for polymerizing resin adhesives has been by actual contact of the wood layers with heat-distributing mediums, i.e., by conduction. A quite different method is attracting much favorable attention by induced heat, which is built up in the

wood members by high-frequency radiation. This generation of heat within materials through electrostatic or electromagnetic means is not of recent origin. As a matter of fact, electrotherapy has been practiced by the medical profession for many years. In this connection "artificial fever," or heat, is generated in the part of the body to be treated merely by exposing that portion to a high-frequency electrostatic field. Actually the heated material forms the dielectric between two plates of a condenser through suitable coupling to a high-frequency generator.

Basic Theory

Briefly, this phenomenon of heat generation can be explained as follows. All matter is composed of molecules, which in turn consist of atom combinations. Atoms are electrical particles, and each atom has a positive charge about which the negatively charged electrons revolve, moving in mixed orbits. When these atoms are subjected to a high-frequency electrostatic field, the electrical particles of the atom are alternately attracted and repelled by the rapidly changing electrostatic field. This periodic orbit distortion results in friction, which manifests itself as heat. The energy converted into heat, due to the molecular friction, is supplied by the high-frequency apparatus.

Development

About 1935 a group of scientists became interested in the problem of heating non-conducting materials for industrial requirements, by means of high-frequency electrostatic currents. Apparatus was constructed in the laboratory, consisting essentially of a transformer bank, rectifier tubes and an oscillator, with a power input of some 60 kilowatts. Tests were carried out on drying tobacco in hampers, on the destruction of infestation of grains, and on sterilizing surgical bandages, with most encouraging results. Still later followed research on heating wood for adhesive and drying purposes. When wood is exposed to a high-frequency field, energy is absorbed by the wood from the field, and the entire wood structure rises rapidly and uniformly in temperature, depending on the time of exposure to the field, to the field strength, and to the electrical characteristics of the product.

When a combination of wood and adhesive was placed in such a field, it was found that the adhesive reached the polymerization temperature with much lower wood surface temperatures than in the conventional hot-platen press, in which the face veneers became much hotter than did the lines of the adhesive. Such a temperature gradient is inherent in the normal hot-press process, but the high-fre-

quency procedure was found to reverse this gradient, with the hottest spots occurring on the adhesive lines. It was also determined that the temperatures on the adhesive lines were independent of the distance of the lines from the surfaces of the pair of electrodes between which the electrostatic field was maintained. In other words, an adhesive line 6 inches from an electrode would be heated as quickly as one an inch distant. In the case of the conventional hot press, heat penetration of as much as 1 inch is approximately the practical limit, and even at this depth, the face veneers become much too dry.

Advantages

Not only does this induced heat, therefore, eliminate the retardation of heat penetration through the outer veneer layers, and prevent the over-drying of the veneers, but it also shortens the total time of cure of the resin bond in the plywood to the minimum polymerization interval. This shortening of time exposure to heat means that the veneers lose a negligible amount of moisture during the interval of resin polymerization.

Example

A typical example would be the above case of 1-inch penetration (2-inch total thickness), the practical top limit in a hot press, compared with the induced heat process, where such a depth is only the beginning of its effectiveness, and a conservative statement of the results would be:

	Conventional Hot Press	*Induced Heat*
Total time of cure	60 min.	5-10 min.
Temperature of center adhesive line	250°F.	250°F.
Surface temperature	300°F.	225°F.
Moisture loss at surface	5-10%	1±%

While this tabular comparison does not represent either process at its maximum efficiency, it does reveal important trends in the intermediate border zone between them.

It is thus apparent that this process of induced heat provides a useful extension of the depth at which resin adhesive bonds can be polymerized economically, and it may well be a valuable supplement to the conventional hot press. Whether this high-frequency field method will eventually prove to be as convenient and economical as the hot press in normal, thin plywood constructions remains to be determined, and its initial cost and serviceability remain to be demonstrated by actual use in various phases of plywood manufacture.

Typical Diagram

A diagrammatic sketch of the arrangement of the electrodes of a high-frequency field in plywood press operations is shown in Fig. VI. 36. These electrodes are placed on the opposite sides of the plywood assembly, with layers of lumber and veneer alternating with

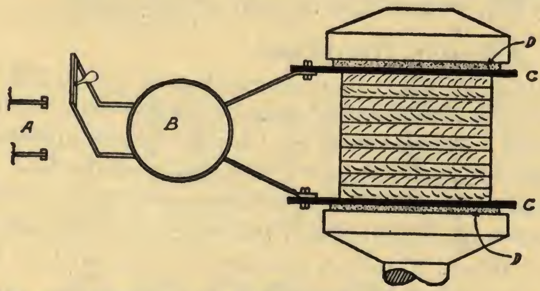


Fig. VI. 36—Application of diathermic heat to plywood bonding.
A—electric service lines. *B*—transformer to high-frequency current. *C*—electrodes, with plywood in field between. *D*—insulation between electrodes and press heads.

the adhesive lines between the charged plates. Pressure must be provided mechanically and independently of the heat sources, and is just as essential as in conventional hot pressing. Under suitable condi-

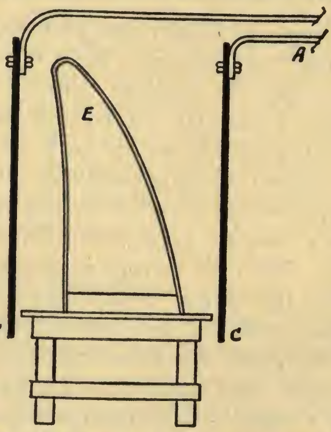


Fig. VI. 37—Arrangement of electrodes with wood assembly in high-frequency field.
A—connections from transformer. *C*—electrodes with high-frequency field between. *E*—wood and plywood assembly.

tions, the lower traveling head of the press may serve as one of the electrodes.

It has been pointed out that there are a number of wood construc-

tions in which the application of heat for resin cure, in an adhesive joint, by normal hot plates is impractical, such as dowel, dovetail, mortise and tenon, and other assembly constructions. The making of "swell" drawer fronts, or curved buffet doors, where wood cores are sawn from large laminated blocks, is another instance. In such cases the induced heat process may be used advantageously.

Assembly Adhesive Operations

Still another probilem in resin bonding is the hollow part of an airplane or boat, often with a plywood surface on a skeleton framework or form. The pressure can usually be accomplished by nails, screws, bolts, straps, wedges, "C" clamps and the like. If such an assembly can be placed in a high-frequency field for a few minutes, the resin bonds can be cured and subsequent and dependent assembly operations contiued. Such a procedure is indicated in Fig. VI. 37, applied to an airplane sub-assembly.

There are many other useful applications of this induced heat process to wood and plywood assembly, which will increase in scope and effectiveness as the process undergoes practical development in the industrial field and becomes better understood.

FLEXIBLE-BAG PRESSURES

There are many types of veneer and plywood constructions where the standard hot press, with pressure from one direction only, is not suitable. In some cases the quantity demands do not justify especially designed pairs of properly curved and heated dies, or in other instances the curved products are of such an irregular shape that pressure must be exerted simultaneously in several directions. The flexible-bag technique, while it has been known and used for many years, has had very limited applications in the plywood industry until quite recently. With the advent of thermosetting phenolic and urea resin adhesives, the earlier difficulties of the slow-setting glues have been overcome, and the use of this process is now growing rapidly. It is to be noted that this flexible-bag pressure is of the order of fluid pressure (i.e., exerted in a perpendicular direction to any curved surface) and therefore more efficient than other methods of applying multi-directional pressure in the bonding of adhesives. The fundamental principle involved is that of using an inflated or deflated bag as one of the halves of a pair of molding dies or forms. There is not only the saving in matching up a pair of dies, where the intermediate distance between halves must be very accurately determined, but in some cases the dies may be wholly eliminated.

There are a number of patents in this field, and those who desire

to use any of these processes should make careful investigation before proceeding.

This type of fluid pressure can be applied in many ways. A few of the principal applications will be outlined briefly and illustrated. In general, bags are of natural or artificial rubber, with woven cloth inserts, and are flexible rather than extensible. They must be highly resistant to repeated exposure to heat.

Vacuum Bags

These consist of wide-mouthed bags that can be clamped shut, and the air exhausted (through "B") by a vacuum pump. A typical cross-section is shown in Fig. VI. 38, in which a series of wood-core pilasters, for furniture or radio cabinets, are being faced with veneer. These wood moldings, "A," are accurately machined and very thin

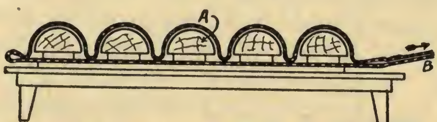


Fig. VI. 38—Molding with vacuum bags.
A—solid wood pilasters to be veneer faced. *B*—vacuum exhaust outlet.

veneers are used, sometimes laid at an angle of 45° to the axis of the curve. After the adhesive is applied, the parts are assembled (often tacked or stapled together to prevent slippage), and inserted in the bag, where the pressure may be reduced to an approximate vacuum. While this pressure cannot exceed 15 pounds, the manual pressing and rubbing of the veneer against the cores, through the bag, will help to smooth down the curves. Quick-setting glues or adhesives, without heat, are essential, and those of a distinctly tacky nature hasten this operation.

Pressure Bags, Applied Outside

In this case the bags exerting the pressure are outside of the plywood assembly. One side of the flexible bag is against the plywood, while the other side is held by a rigid outer shell at points opposite the plywood product. Bags may be of various shapes and in some cases several bags may be used, filled separately or interconnected.

The application of this method to moldings (similar to those shown in Fig. VI. 38) is shown in the cross-section of Fig. VI. 39. The bags are essentially sections of a large hose, with inlet at one end and outlet at the other. Work is inserted while the bags are deflated, the assembled items often being held in place by tacks or staples until the pressure becomes effective. The pressure medium is usually hot

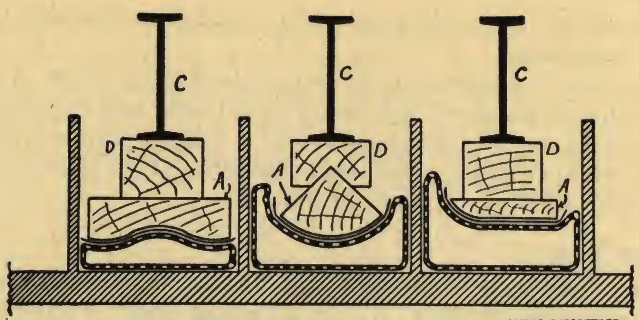


Fig. VI. 39—Pressure-bag process.

A—solid wood pilasters to be veneer faced. *C*—rigid "I" beams holding moldings straight. *D*—spacer blocks of required size to make bag pressure effective.

water, rather than air, to speed up the setting of the adhesive and increase machine production. Pressures of 100 pounds and temperatures of 200°F. are entirely practical, although lower ranges are sometimes used.

This method can also be applied to large units, like the hull of a small boat, or substantial parts of an airplane fuselage or wing. Such an application to a half fuselage is shown in Fig. VI. 40, where the flexible bag, "F," is essentially a rubber mattress (without cells), restrained by the steel outer shell, "G," and exerting its pressure

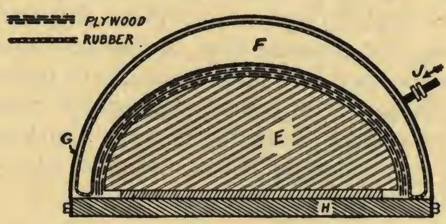


Fig. VI. 40—Molding a half fuselage.

E—inside mold, may be metal with steam pipes, or framed wood with slots for rings and longerons. *F*—rubber bag, inflated with air, steam or hot water through inlet *J*. *G*—outer steel shell, bolted to base *H*.

against the plywood assembly that is shaped over the form, or mold, "E." This mold may be heated by steam, or the heat may be provided by the pressure medium. If a skeleton wood frame is used for "E," it is usually recessed for the rings and longerons that are bonded inside of the plywood. The pieces of veneer are carefully cut to shape so that each layer will be complete, without gaps or overlapping, during the process of bonding into plywood and to the frame members. The various parts are held in place temporarily by tacks, tape, steel bands or wire. The fluid medium may be air, steam

or hot water, and due provision must be made for rapid filling, "J," and in some cases for circulation. The outer shell, "G," is usually semi-cylindrical to provide for a variety of shapes, but sometimes conforms to the shape of the product, as in the case of boat hulls, where the keel and ribs are inserted in the mold.

Pressure Bags, Applied Inside

This is essentially the reverse of the method described immediately above, with the flexible bag inside the product, and is better adapted to complete units, as well as giving smoother exterior surfaces, which rest directly against the mold. This is a distinct advantage in airplane parts, where free air flow reduces the power requirements. It is particularly useful where several layers of 2-ply are to be glued, after bending, into a multi-ply, such as a rigid leading edge of an airplane wing, as shown in Fig. VI. 41. This particular construction does not lend itself readily to the method shown in Fig. VI. 42, since there may be inadequate pressure at points where the layers of 2-ply cannot be supported by the framework.

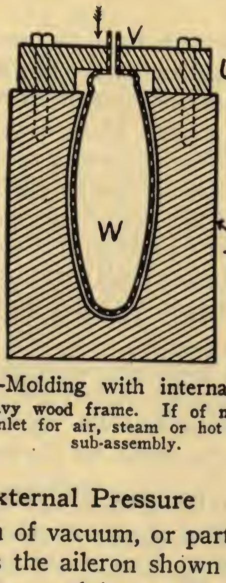


Fig. VI. 41—Molding with internal bag pressures.
T—outside mold, metal or heavy wood frame. If of metal, may be steam heated. *U*—sturdy cap, bolted to *T*. *V*—inlet for air, steam or hot water. *W*—rubber bag, inside of sub-assembly.

Vented Bags, with External Pressure

This is a combination of vacuum, or partial vacuum and pressure. Sub-assemblies, such as the aileron shown in Fig. VI. 42, are temporarily attached together and inserted in a wide-mouthed flexible bag that can be tightly closed and inserted in a pressure tank. The air pressure inside the bag can be partially exhausted by a vacuum pump, or in some cases merely vented to the atmosphere through "P." The pressure medium enters at "Q," and may be air (in the

case of cold-setting adhesives), hot water or steam, or a combination thereof. Pressures and temperatures can be as high as desired for rapid production. While only one sub-assembly is shown in Fig. VI. 42, the pressure tank may be filled with as many units as can be accommodated, each bag being individually vented. The time element required to insert sub-assemblies and to fill the pressure tank is often such that small tanks prove to be the most efficient for small units of production.

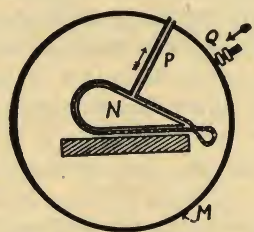


Fig. VI. 42—Molding sub-assembly parts in pressure tanks.
M—outer steel tank. *N*—sub-assembly, inside of rubber bag. *P*—vent to atmosphere, or vacuum connection. *Q*—pressure connection for steam.

Conclusions

These several molding methods have distinct possibilities, and there are many other possible combinations. The mechanical adaptations are not difficult, but the chief obstacle to broader use is the lack of standardization in aircraft design. There is no reason why these rubber-bag methods should not find extensive use in airplane sub-assemblies, when and if some standardization becomes well established. Whether the processes will be adapted to large units like fuselage halves or complete planes is a problem that time and experience will reveal. The excellent weight/strength ratios of plywood and the smooth exteriors, without rivets, both add to the air effectiveness of such types of planes.

The resin adhesives are admirably adapted to these molded plane designs. If sufficient heat and pressure are attainable the phenolic liquid resins are preferable, while the urea resins will give good results if conditions are unfavorable for the use of phenolics.

SCARF JOINTING

The technique of increasing plywood areas has become important owing to the rapidly growing demand for large, multiple sheets of plywood in boat hulls and glider aircraft.

Fundamentally this is a tapered and overlapping joint, that does not increase the thickness of the veneer layer nor of the plywood sheet, but does preserve its normal strength up to 80% plus. End scarfs are not so strong as edge scarfs. The length of the scarf joint

should be 12 to 20 times the thickness, with 15 usually considered adequate.

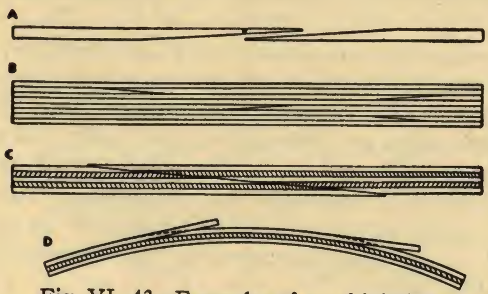


Fig. VI. 43—Examples of scarf jointing.

A—single layer scarf, ratio 15:1. (Note blunt toe.) *B*—laminated spar with scarfed joints in the individual layers, staggered in location. *C*—scarfed joint in plywood, ratio 15:1. (Note that toe rides slightly over the heel.) *D*—scarfing outer layer of molded plywood to simplify fitting; projections are sanded off after adhesive has set.

Scarfed surfaces must be beveled on a true even plane, with a slightly blunt end, since a feathered tip will not adhere well. During the bonding operation the beveled surfaces must be in complete and close contact. The blunt toe of the scarf should ride slightly (1/64 to 1/100 inch) over the heel, as shown in Fig. VI. 43 C, so that adequate pressure is assured and the pressure exerted should be enough to compress the scarfed area slightly. In the case of a single layer joint, as in A, the layers should be planed or surfaced before assembling into B.

Bonding under heat is to be preferred, as it permits the use of phenolic resin adhesives, but cold-setting ureas, as well as casein and animal glues, can be used if heat is not available and extreme durability is not required. Heat can be applied by any of the several processes described elsewhere. It is important that plywood or veneer sheets be firmly clamped in position before heat and pressure are applied at the angling joint to prevent slippage. Since end grain is exposed in the scarf, it is desirable to presize the beveled surfaces with a dilute adhesive mixture before the regular adhesive is applied.

PLYWOOD FINISHING

Dimensioning

The equipment and methods used in dimensioning plywood are closely related to those employed in other woodworking operations. Hence the descriptions which follow will relate only to special provisions for plywood that differ from those for lumber.

In general, any sawing on plywood is partly crosscutting and partly ripping, due to the alternating grain directions. This requires a combination circular saw blade, with groupings of fine teeth for the cuts across the grain, alternating with larger teeth and deeper throats for that part of the cut that is with the grain. In the case of band

saws, a compromise type of tooth is required. These are well recognized by saw makers and filers, and the problem need only be suggested here.

It is quite customary to arrange plywood dimension saws in tandem, so that the intermediate operator may tail the first saw and feed the second, a total of three men for two saws. Most plywood saws trim both edges or both ends in the same operation. Usually the longer cut is made first, as in the case of stock panels, but this order may be reversed sometimes for convenience. Tandem saw rigs are often equipped with the short direction saw at right angles to the saw used on the long dimension, as an economy in handling, as well as in factory space.

For center matched panels with figured faces, one or more pointers are used, exactly central between the saws, to guide the feed.

Several thicknesses of thin panels, up to an aggregate of 1 inch, are often sawed at one operation, but must be held flat.

In the case of thin plywood, 1/8 inch and less, the rough dimensioning may be done on veneer clippers. This is especially applicable to aircraft plywood.

Sanding

This operation, like dimensioning, is essentially the same on plywood as on lumber, and requires few special suggestions.

In general, the back side of the plywood is sanded first, to remove the tape and clean up the surface. This gives a better foundation for the accurate sanding of the face. Drum sanders, or those of the endless bed type, are usually used on commercial plywood faces, or where the figured faces are rather plain in character. In the case of highly figured and combination faces, belt sanding is preferable to prevent sanding through to the crossbands.

In the case of structural grades of plywood, such as fir and pine, it is customary to sand the two sides simultaneously.

The fineness of the sandpaper, in any progressive sanding machine, varies from coarse to fine, from where the plywood enters to where it leaves.

The use of the tapeless splicer, a machine for the edge gluing of the veneer (see page 136), greatly reduces the amount of sanding, as the tape removal is eliminated. Its economy in this direction is more important than the saving in the cost of the tape.

Some plywood manufacturers use a scraper, rather than a sander, on the less figured types of veneers. The operation is quicker and less veneer is removed, but it requires unusual skill and accurate machine set-ups and adjustments.

The sanding of curved plywood presents problems of special attachments, for inside and outside sanding. A type of saddle for sanding convex, or outer curves, is shown in Fig. VI. 44. The cradle

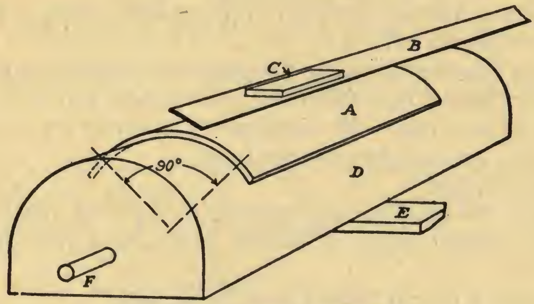


Fig. VI. 44—Saddle for sanding.
A—curved plywood to be sanded. *B*—sand belt. *C*—sander block. *D*—oscillating saddle. *E*—operator's handle for swinging saddle while sanding. *F*—saddle shaft.

shown in Fig. VI. 45 is for sanding the inside or convex surface. Both are usually attached to belt sanders, on which the idle side of the belt is below.

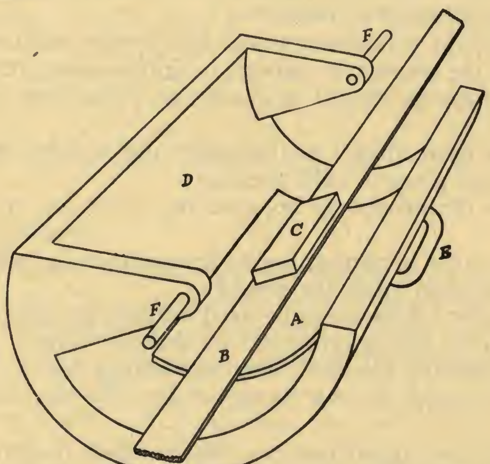


Fig. VI. 45—Cradle for sanding.
A—curved plywood to be sanded. *B*—sander belt. *C*—sander block. *D*—rocking cradle. *E*—operator's handle to rock cradle while sanding. *F*—cradle shaft.

In the case of plywood products with recessed centers, such as Toastmaster trays, it is customary to sand the 2-ply faces and backs before the recess is formed in the second or final bonding and shaping operation.

QUESTIONS

1. What are the principal departments in a plywood operation?
2. What is the purpose of redrying veneer?
3. Tell the difference between clipping and jointing, and when is each process employed?
4. Discuss the use of taping machines and tapeless splicers.
5. What is meant by tenderizing veneer, and why is it done?
6. What is the reason for toughening face veneers by dipping?
7. Describe combination veneer faces.
8. What is inlay?
9. What is the purpose and method of 2-plying faces?
10. Name several types of lumber cores, and the kind of joints used.
11. How and why can lumber cores be vented?
12. Describe methods of assembling and gluing core strips, in a revolving clamp, or with resin adhesives.
13. What is the method and reason for saw slotting lumber cores?
14. Describe the mechanical equipment used with conventional glues in cold pressing.
15. Demonstrate the magnitude of the problem of removing glue solvents from plywood in redriers.
16. What are the principal types of hot presses and pumps?
17. Indicate the necessary cautions in dimensioning resin film.
18. What provision should be made for initial flow in film bonding?
19. How do resin mixers and spreader differ from those used for the conventional glues in cold pressing?
20. Describe the process of hot pressing, from lay-up to discharge from press.
21. What are the important points in conditioning hot-pressed plywood after removal from the press?
22. What resin adhesive can be used without hot presses and how?
23. Describe the plying up of curved drawer fronts.
24. Discuss making plywood with cold-setting resins.
25. What is meant by the aging of an adhesive, and why is it important?
26. Outline the high-frequency electric field method of curing resin bonds.
27. In what type of constructions does it find its best utility?
28. How can it be applied to assembly work?
29. Outline the advantages of flexible-bag pressures.
30. Describe four principal methods of using flexible bags.
31. To what types of work is the bag process best applied?
32. Describe briefly the dimensioning and sanding of plywood.
33. What equipment is used for sanding curves?

SECTION SEVEN

HIGH-DENSITY PLYWOOD

DENSITY OF WOOD AND PLYWOOD

Definitions

Normal wood density varies widely with the species, and moderately within a species, such as the differences between heartwood and sapwood. **Density** is defined as the mass of a body per unit of volume. When expressed in the metric system, it is numerically equal to the **specific gravity** of the same substance.

The strength of a wood is indicated by its density. The density of the actual wood substance, i.e., the material of which the cell walls are composed, is substantially the same for all species, and its value in the metric system is about 1.46, or its specific gravity. Woods differ in specific gravity because of variation in the size of the cell cavities, in the thickness of the cell wall, and in the amount of gums, resins and other extractives. The amount and distribution of wood substance are the determining factors in the strength of a piece of wood.

As examples among native woods, air-dried basswood has an average specific gravity of .37 and hickory .73, while among imported species balsawood has a specific gravity of .12-.16, and lignum vitae 1.25.

Compressed Wood

It has long been recognized that compressed wood is stronger than normal wood, but little commercial success has attended the many attempts at compressed wood technique. Wood compression presents a number of problems, among which the following are of importance. Wet wood compresses more easily and faster than dry wood, but both recover much of their reduced dimension when the pressure is released. Heat facilitates the compression and cold retards it. If wood of any substantial thickness is compressed, it is found that a greater degree of compression occurs in the outer than in the central layers. Wood may crush to a point of fibre separation, particularly if the pressure is exerted at a sharp angle to the growth rings. Hence some type of impregnant, with adhesive characteristics, is essential to supplement the natural cohesiveness of the wood

fibres. As a consequence of these many problems, there has been a minimum of encouragement to those interested in the practical compression of solid wood.

Normal Plywood Pressures

It has been pointed out earlier in this treatise that it is essential to bring veneer surfaces into intimate contact to secure an adequate plywood bond with the adhesives that are described. In the case of cold-setting glues and adhesives, it is possible to exert too much pressure, so that the adhesive is squeezed out and a "starved joint" is likely to occur. In other words, the amount of the adhesive is insufficient for the normal soaking of the adhesive into the wood while under pressure, and still leaves enough on the joint line for a proper grip. Hence, super pressures were not practical with cold-setting glues and adhesives.

In the case of heat-reactive resin adhesives the problem is somewhat different, as the bond is completed (i.e., the adhesive attains its initial grip) in a matter of minutes, compared with the hours in clamps required with cold-setting adhesives. Furthermore, resins require more pressure than the cold-setting glues for the development of maximum joint strength. It has, therefore, been customary to use with resin adhesives approximately double the pressure which has been considered adequate for the cold-setting glues: pressures are increased from a 75-100 pound range to 125-200 pounds. Even at these higher pressures there is little reduction in the thickness of the plywood assembly, usually from 5 to 10%, for which due allowance must be made in the original thickness of the various layers. Very few of the hot presses now installed are sturdy enough to exert specific pressure on the plywood, over the whole platen area, beyond 200 to 250 pounds. It was also found that the higher pressure, when applied to less than the full platen area, tended to develop warp in the resulting plywood.

Super Pressures in Plywood

Development work by several pioneer companies had revealed that plywood pressures of 500 to 2000 pounds resulted in a plywood product of greatly increased strength characteristics, provided that hot-pressed resin adhesives were used, and the amount of resin was sufficient to supplement the normal cohesiveness of the wood fibres and to prevent their separation.

There are two principal methods of accomplishing this result, by the use of thin veneers and film resins, or by the use of liquid resins, which permit considerably greater thickness in the veneer layers. In

the case of the resin films, there are distinct advantages in the uniformity of the resin application, in the absence of moisture in the form of glue solvent, and in the simplicity and cleanliness of the operation. The use of a resin liquid is much more complicated, but somewhat thicker veneers may be used. It is necessary to impregnate the veneers under pressure, to predry the surplus solvent before hot pressing to avoid steam blisters, and to contend with the outside coating of resin that produces a surface sheen and is likely to adhere to the cauls or hot plates. The intermediate handling of resin-saturated veneers adds to the difficulties of this method. The limited existing data indicate that greater strength factors may result from the impregnation process, but that there is a wide range of utility for the products of the film method. As further experience accumulates, it is quite possible that the less costly and simpler film method may be developed to meet all except the most exacting uses.

An important factor in both processes is to cool the plywood to approximately 180° F., before the release of pressure. Even though a thermosetting resin is employed, there are certain volatile items in the hot-pressed plywood, resulting from adhesive solvents or wood constituents, that tend to "puff out" the plywood surfaces somewhat irregularly, although not seriously affecting the strength factors. The indications are that such cooling is unnecessary at pressures of 500 pounds or less.

In general, it may be said that the use of film results in wood reinforced with resin, with wood characteristics predominating, while the use of liquid resin produces a plastic reinforced with wood, more closely approaching the physical characteristics of the plastics.

High-density Plywood

This new type of plywood, bonded under the higher range of pressures, has been given a variety of titles, "Improved Wood," "Tegowood," "Jicwood," "Pregwood," "Compreg," "Super-pressed Plywood," and the like. However, it is becoming increasingly clear that the strength characteristics very closely follow the density or specific gravity of the product, and are largely independent of species and constructions. Authorities are coming to feel that **High-density Plywood** affords the best description, and is preferable to any of the other titles, some of which are more or less proprietary and protected by patents and trademarks.

The growth of knowledge regarding this product will undoubtedly tend to clarify the situation and to establish a suitable descriptive title.

VARIABLES IN HIGH-DENSITY PLYWOOD

There is a considerable amount of literature available on the strength characteristics of this high-density plywood, as can be noted in the Bibliography in Section XII. In the main these references describe highly specialized individual projects, and do not give a broad perspective of the product, nor develop the basic principles that distinguish this product from other types of plywood.

A detailed, but somewhat preliminary study of this high-density plywood was presented to the Wood Industries Division of the American Society of Mechanical Engineers in the fall of 1939, from which the following excerpts have been taken.

Extent of the Investigation

In this series of preliminary tests it was determined to study the effects of the different major variables, keeping in mind the reasonable availability of raw material and of the necessary equipment, as well as such cost factors as would make the product attractive to industry. Hence, common species of wood were used in thicknesses that were easily obtainable.

Careful consideration was given to the type of thermosetting synthetic resin and to the method of its application. The phenol-formaldehyde type was chosen because of its proven durability under many conditions. The reason for selecting the film type, in preference to the liquid form, was its simplicity of application and the ease of control as to the amount used.

Major Variables Considered

The following major variables and the determination of their effects were considered:

1. Thickness of veneer layers, ⅛ to 1/48 inch.
2. Common species of wood, such as birch, yellow poplar, and red gum.
3. Increasing pressures, 200 pounds to 1500 pounds.
4. Number of layers of resin film, one to three.
5. Cross layer frequency, alternate, every 5th and every 10th.

When the influence of the above variables was determined, it was possible to develop, in a preliminary form, comparative tabulations:

6. Comparison of equally dense plywood of different species.
7. Method of determining strength factors for design purposes.
8. Comparison of super-pressed plywood with extra dense solid woods.

The different constructions selected will be noted in the tables that follow. In the interest of simplification, some intermediate stages were omitted, but in all cases maximum, minimum and one or more intermediates were used.

Plywood Fabrication

Veneers were rotary cut or sliced, standard grade, clear, and without physical defects such as knots and splits. The veneers were assembled and the plywood hot pressed under normal factory conditions of temperature and humidity, so that all veneer contained from 7% to 10% moisture content. The bonding temperature was 300°F. ± 5°. Sufficient sheets of veneer were used so that the resulting plywood would slightly exceed one inch in final thickness after pressing. Bonding time was 30 minutes under full temperature and pressure. All series of samples, except two so indicated, were made of an odd number of plies, with each adjacent sheet at right angles to its neighbor, the customary standard plywood construction. The two special series of samples had 5 (or 10) parallel layers, then one crossed, followed by 5 (or 10) parallel, etc., the parallel layers being outside on both face and back to preserve balance. All series of samples were made with single layers of resin film, except one group, where double and triple layers were used.

Certain of the samples, indicated by an (#), were cooled under indicated pressure by circulating cold water through the press platens, instead of steam, for 15 minutes. This procedure caused no significant difference in strength values, but was found to secure more uniform thickness of the panels than when air cooled after removal from the press.

Birch was used for most of the tests, since it has been extensively used as a comparative standard at the Forest Products Laboratory at Madison, Wisconsin. A few samples of yellow poplar and red gum, all easily obtainable veneer woods, were tested also.

Test Procedure

The samples of super-pressed resin plywood were cut into convenient sizes for the testing machines, as shown in Fig. No. VII. 1. From three to six samples were tested in every series and the results averaged. Tests were made in compression, tension, and shear, the latter both parallel and perpendicular to the grain of the face veneer. Since it was found that these two shear tests gave substantially equal results, they are averaged in the tables that follow. All

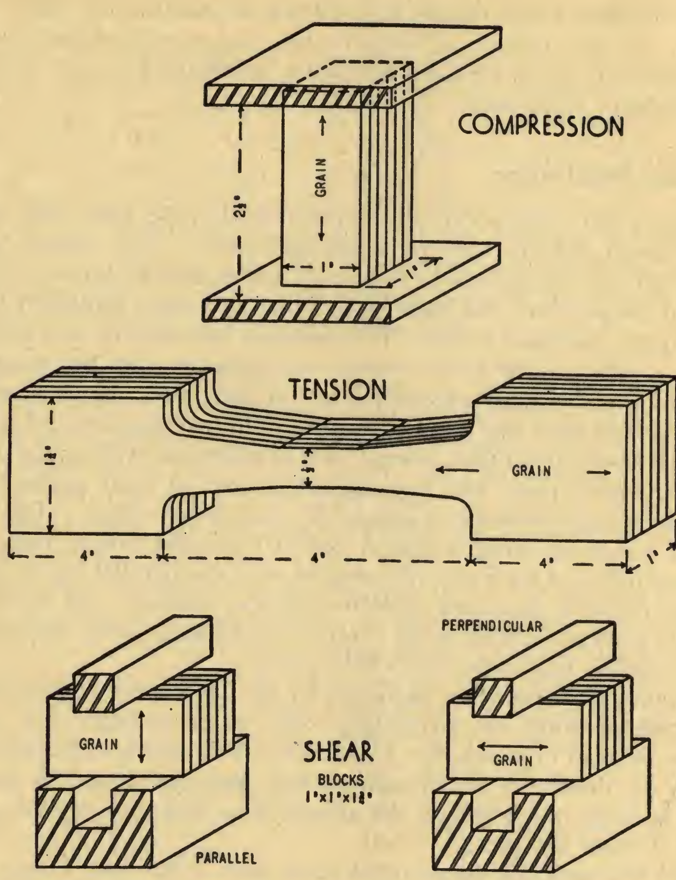


Fig. VII. 1—Compression, tension, and shear plywood test specimens.

results are expressed in pounds per square inch. The figures given are those obtained for the maximum loads at the breaking points. The data for solid wood were taken from the *Wood Handbook*, published by the U. S. Forest Products Laboratory, Madison, Wis., 1935. They indicate stresses in pounds per square inch at the proportional limit. The shear values shown in solid wood were parallel to the grain, the weakest direction. The strength factors of solid wood and plywood are not strictly comparable, but this fibre stress at the proportional limit in solid wood is the most available figure to compare with breaking stresses in plywood of this type.

Effect of Thickness of Veneer Layers

Tests were performed on ⅛-inch, 1/16-inch and 1/48-inch birch, with specific pressures of 500 pounds, all alternate cross-layered.

Table VII. 1
Effect of Veneer Thickness

Key	*Veneer Thickness*	*Layers Used*	*Specific Gravity*	*Compression*	*Tension*	*Shear*
A	Solid Birch	1	.63	6,200*	10,100*	2,020*
B	1/8″ Birch	9	.77	7,890	11,840	6,060
C	1/16″ Birch	17	.72	7,980	13,920	6,330
D	1/48″ Birch	69	1.05	11,720	19,160	11,540
	Increases					
	D over A*	....	67%	89%	90%	470%
	D over B	....	46	49	62	90

* Strength factors of solid wood and plywood are not strictly comparable.

It may be concluded that substantial strength increments cannot be expected in either ⅛-inch or 1/16-inch veneer, but are found in 1/48-inch veneer constructions, as shown in Table VII. 1. Part of this increased strength may be caused by the greater number of veneer and resin film layers. It is to be anticipated that 1/32-inch and 1/40-inch strength values could be approximately interpolated

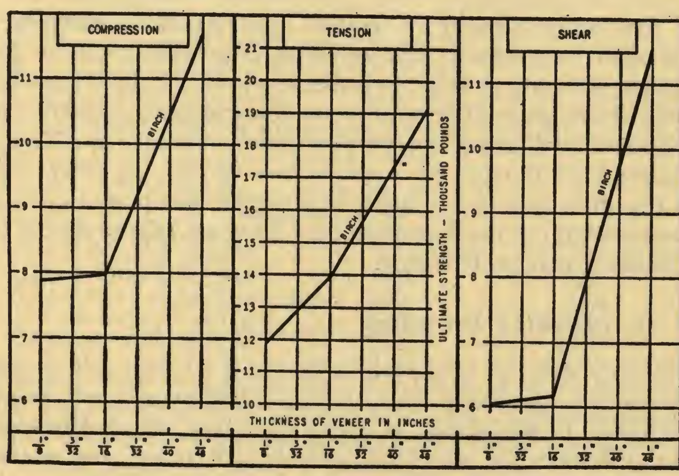


Fig. VII. 2—Strength increments of veneer thicknesses.

on the chart, Fig. VII. 2, until more detailed information is available.

Effect on Common Species

This series of tests was made on three common veneer species, birch, yellow poplar and red gum, the results of which are given in Table VII. 2. Available thicknesses were 1/48 inch, 1/45 inch and 1/40 inch respectively. Specific pressure was 500 pounds with alternate cross layers.

Table VII. 2
Results on Common Species

Construction	Specific Gravity	Moisture Content	Compression	Tension	Shear
A Solid Poplar.........	.40	12.0%	3,550	6,100	1,100
B 77/45″ Poplar#	.82	5.3	8,460	13,420	8,220
Increase B/A........	105%	....	138%	120%	647%
C Solid Gum...........	.49	12.0%	4,700	8,100	1,610
D 45/40″ Gum.........	.73	6.9	6,920	11,330	6,610
Increase D/C........	49%	....	47%	40%	310%
E Solid Birch..........	.63	12.0%	6,200	10,100	2,020
F 69/48″ Birch#........	1.05	7.7	11,720	19,160	11,540
Increase F/E........	67%	....	89%	90%	470%

Cooled 15 minutes under pressure.

The low initial density of poplar provides an opportunity for greater relative increase in strength than is possible with the denser species, but ultimate strength is indicated to be far below birch and definitely above gum. The results are low on gum, possibly caused by the greater thickness of the veneers. At the pressure of 500 pounds per square inch during the manufacture of the plywood, neither poplar nor gum approaches birch in strength, but poplar on a relative basis with birch is closer than in solid wood. Gum, on the other hand, shows a reverse tendency.

Effect of Increasing Pressures

These tests were on 1/48-inch birch and 1/45-inch yellow poplar, with pressures increasing from 200 to 1500 pounds, all alternate cross-layered. In this series an opportunity was afforded to observe a slight difference in strengths between air-cooled and pressure-cooled specimens.

Table VII. 3
Effect of Increasing Pressures

Construction	*Specific Gravity*	*Moisture Content*	*Specific Pressure*	*Compression*	*Tension*	*Shear*
A Solid Birch.........	.63	12.0%	....	6,200	10,100	2,020
B 57/48″ Birch........	.77	6.6	200	8,580	12,550	7,240
C 69/48″ Birch#.......	1.05	7.7	500	11,720	19,160	11,540
D 81/48″ Birch#.......	1.30	8.3	1,000	14,220	25,740	16,180
E 85/48″ Birch#......	1.36	8.7	1,500	14,270	28,490	15,910
F 85/48″ Birch........	1.35	8.2	1,500	14,540	25,030	16,360
Increase E/A.......	116%	....	....	131%	182%	688%
Increase E/B.......	77%	....	....	66%	127%	120%
Increase D/B.......	69%	....	....	66%	105%	123%
G Solid Poplar........	.40	12.0%	....	3,550	6,100	1,100
H 77/45″ Poplar#.....	.82	5.3	500	8,460	13,420	8,220
I 105/45″ Poplar#....	1.32	7.7	1,500	14,540	23,570	16,460
Increase I/G........	230%	....	....	310%	286%	1396%

Cooled 15 minutes under pressure.

The significant features of this series (Table VII. 3) are that, in birch, strengths increase slowly above 1000 pounds pressure. There is a small gain, most marked in tension. Such further increases may be expected above 1500 pounds. The percentages of increased strengths are shown in several ways:

E/A, the ratio of 1500 pounds pressure over solid wood.

E/B, actual tested strength increments of super-pressed plywood at 1500 pounds over normal plywood at 200 pounds. This is an indication of trends that may be expected in this high pressure technique.

D/B, the same as E/B, but between 1000 pounds and 200 pounds.

While additional layers of veneer and film are required for the higher pressures to secure the same final thickness, this percentage of increased initial bulk and cost is distinctly less than the strength increments, viz.:

Reference, Table VII.3	E/B	D/B
Pressure ratio	1,500/200	1,000/200
Extra material required	50% (85:57)	42% (81:57)
Specific gravity increase	77%	69%
Compressive strength increase	66%	66%
Tensile strength increase	127%	105%
Shear strength increase	120%	123%

Equipment costs at 1000 pounds are nearly double those at 200 pounds. Increased equipment costs above 1000 pounds are considerably more. From a commercial standpoint it would appear that this limit of 1000 pounds provides a reasonable product cost, with outstanding strength values.

It is to be noted that the strength values of birch and poplar are far apart at 500 pounds, but are close together at 1500 pounds. More poplar layers are required for a given ultimate thickness than in birch, because of greater compressibility. Yet, the availability of the different species in the manufacturing area may influence the economic aspects.

The result of intermediate pressures can be reasonably interpolated in the chart (Fig. VII. 3), until more comprehensive data are available.

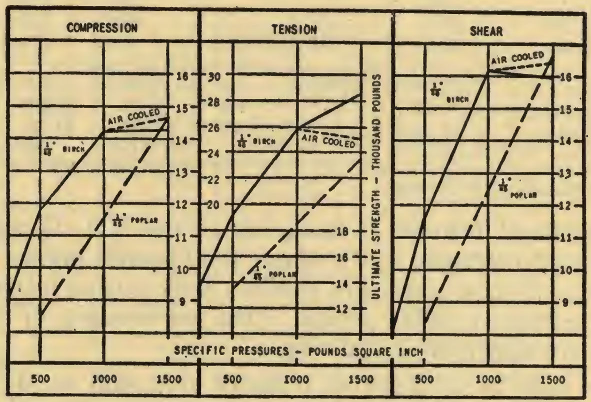


Fig. VII. 3—Strength values of plywood at various bonding pressures.

Effect of One, Two or Three Layers of Resin Film

This series at 500 pounds pressure, performed on 1/48-inch birch, with alternate cross layers, indicated the results shown in Table VII. 4. It is the only series where more than one layer of film was used.

Table VII. 4
Effect of Layers of Film

Construction	*Specific Gravity*	*Moisture Content*	*Film Layers*	*Compression*	*Tension*	*Shear*
69/48″ Birch#	1.05	7.7%	Single	11,720	19,160	11,540
73/48″ Birch#	1.105	6.9	Double	13,300	19,800	14,520
63/48″ Birch	1.05	6.3	Triple	12,590	16,930	12,280

Cooled 15 minutes under pressure.

Three layers are better than one, except in tension, while two layers of film between veneers seem to be much better than one. The

first combination, however, does not appear to have any special advantages. There is a possibility that tests with multiple layers of film with thicker veneers may modify this conclusion.

Influence of Cross-layer Frequency

Samples for this series were made of 1/48-inch birch, under 500 pounds pressure, with cross layers as indicated in Table VII. 5. It is the only series where standard cross-layering was not followed.

Table VII. 5
Effect of Cross-layer Frequency

Construction	*Specific Gravity*	*Moisture Content*	*Cross Layers*	*Compression*	*Tension*	*Shear*
69/48″ Birch#	1.05	7.7%	Alternate	11,720	19,160	11,540
67/48″ Birch	.88	7.3	Every 5th	12,130	19,370	8,480
67/48″ Birch	.89	7.7	Every 10th	13,040	19,920	8,370

\# Cooled 15 minutes under pressure.

The slight increase of tensile and compressive strength, caused by the higher proportion of lengthwise layers, is consistent, but not significant. The loss in shear strength could be expected.

Comparison of Equal-density Plywood

Some of the series of tests to determine the effect of major variables indicated the similarity of strength values in constructions of approximately the same specific gravity, as shown in Table VII. 6. So far as comparisons were available, the evidence points toward a consistent and close relation between specific gravity and tensile, compressive and shear values, both in birch and yellow poplar. All samples cited in Table VII. 6 were alternate cross-layered with

Table VII. 6
Comparison of Equal-density Plywood

Construction	*Specific Gravity*	*Moisture Content*	*Specific Pressure*	*Compression*	*Tension*	*Shear*
81/48″ Birch#	1.30	8.3%	1,000	14,220	25,740	16,180
85/48″ Birch#	1.36	8.7	1,500	14,270	28,490	15,910
85/48″ Birch	1.35	8.2	1,500	14,540	25,030	16,360
105/45″ Poplar#	1.32	7.7	1,500	14,540	23,570	16,460
57/48/ Birch	.77	6.6%	200	8,580	12,550	7,240
77/45″ Poplar#	.82	5.3	500	8,460	13,420	8,220

\# Cooled 15 minutes under pressure.

single layers of film. How far this consistency may extend into other species, such as softwoods (conifers), as well as those with varying thickness of veneer, remains to be investigated.

Method of Predetermining Strength Factors for Design Purposes

The strength factors of the various constructions, segregated according to tension, compression and shear, can be arranged in tabular form, as in Table VII. 7, indicating the type of construction that will provide the necessary strength. With a later and more comprehensive series of tests on plywood of different species and thicknesses of veneers and varying pressures, many intermediate strength factors can be made available. With such a table, designers can

Table VII. 7

Predetermining Strength Values of High-density Birch Plywood

Type of Stress	*Veneer Thickness*	*Cross Layers*	*Film Layers*	*Specific Pressure*	*Pounds per Square Inch*	*Note Below*
Compressive.........	1/8″	Alternate	Single	500	7,890	
	1/16″	Alternate	Single	500	7,980	
	1/48″	Alternate	Single	200	8,580	
	1/48″	Alternate	Single	500	11,720	(2)
	1/48″	Every 5th	Single	500	12,130	(3)
	1/48″	Every 10th	Single	500	13,040	(3)
	1/48″	Alternate	Double	500	13,300	
	1/48″	Alternate	Single	1,000	14,220	
	1/48″	Alternate	Single	1,500	14,540	(1)
Tensile..............	1/8″	Alternate	Single	500	11,840	
	1/48″	Alternate	Single	200	12,550	
	1/16″	Alternate	Single	500	13,920	
	1/48″	Alternate	Single	500	19,160	(2)
	1/48″	Every 5th	Single	500	19,370	(3)
	1/48″	Alternate	Double	500	19,800	
	1/48″	Every 10th	Single	500	19,920	(3)
	1/48″	Alternate	Single	1,000	25,740	
	1/48″	Alternate	Single	1,500	28,490	(1)
Shear...............	1/8″	Alternate	Single	500	6,060	
	1/16″	Alternate	Single	500	6,330	
	1/48″	Alternate	Single	200	7,240	
	1/48″	Every 10th	Single	500	8,370	(3)
	1/48″	Every 5th	Single	500	8,480	(3)
	1/48″	Alternate	Single	500	11,540	(2)
	1/48″	Alternate	Double	500	14,520	
	1/48″	Alternate	Single	1,000	16,180	
	1/48″	Alternate	Single	1,500	16,360	(1)

Notes: 1. Increase of pressure, 1000 to 1500 lb., gives little added strength.
2. Basic standard of this series of tests.
3. Difference between crossing every 5th and 10th layer not significant.

select the construction, species, thickness and pressure that will meet most economically the immediate problem.

Comparison with Extra-dense, Solid Woods

Certain extra-dense woods with high specific gravity have a rather limited use. Ordinarily, such woods are available only in small sizes, many of them are imported, all of them are difficult to dry without serious checking, and the cost is often unreasonably high. The proportions of a well-designed, super-pressed plywood construction may be predetermined and the product be made available in comparatively large sizes. Prompt delivery and adequate dimensions will usually offset any moderate cost difficulties. In the case of some solid woods, with unusual qualities, such as the oil content of lignum vitae for bearings, due allowance may be made.

Several high specific gravity woods are shown in Table VII. 8, as well as super-pressed plywood, for the purpose of comparison.

Table VII. 8
Extra-dense Normal Solid Woods

Species	**Specific Gravity*		
	Range		*Average*
Apple	.66 to	.84	.75
Beech	.70	.90	.80
Boxwood	.95	1.16	1.05
Dogwood	.68	.77	.72
Ebony	1.11	1.33	1.22
Hickory	.62	.78	.70
Hornbeam	....	....	.75
Lancewood	.68	1.00	.84
Lignum Vitae	1.17	1.33	1.25
White Oak	.69	.86	.77
Satinwood	....	....	.95
Teak	.66	.98	.82

Approximate Equivalents in Super-pressed Plywood

***Construction*	*Film Layers*	*Specific Pressure*	*Specific Gravity*
17/16″ Birch	Single	500	.72
45/40″ Gum	Single	500	.73
57/48″ Birch	Single	200	.77
77/45″ Poplar	Single	500	.82
69/48″ Birch	Single	500	1.05
73/48″ Birch	Double	500	1.105
81/48″ Birch	Single	1,000	1.30
105/45″ Poplar	Single	1,500	1.32
85/48″ Birch	Single	1,500	1.36

* Specific Gravity from Kent's, 1938 Edition.
** All constructions standard alternate crossings.

Additional Test Data

The information outlined above in the A.S.M.E. report was largely based on plywood made from veneers of 1/48- and 1/45-inch thickness, and for purposes of identification can be called series I.

Supplementary tests were made later at another laboratory on plywood of 1/28-inch veneer, and while much less extensive in scope and inadequate for final conclusions, they present some very interesting features. These are designated as series II, and a comparison of the two series is shown in Table VII. 9. It is to be noted that the

Table VII. 9
Strength Characteristics—High-density Plywood

Table shows stress exerted in pounds per square inch

Series	Type of Stress	Veneer Used	Specific Bonding Pressure				Ratio Increase		
			200	500	1000	1500	500/1000	1000/1500	500/1500
Series I	Compression	1/48″ Birch	8,580	11,720	14,220	14,270	121%	100%	122%
	Tension		12,550	19,160	25,740	28,490	134	111	149%
	Shear		7,240	11,540	16,180	15,910	140	98	138%
	Compression	1/45″ Poplar	....	8,460	....	14,540	...	...	172%
	Tension		....	13,420	....	23,570	...	...	176%
	Shear		....	8,220	....	16,460	...	...	200%
Series II	Bending	1/28″ Birch							
	Modulus Rupture								
	Parallel		....	13,750	14,600	21,400	106%	147%	156%
	Perpendicular		....	12,000	16,300	14,500	136	89	121
	Modulus Elasticity								
	Parallel		....	1,120,000	1,170,000	1,690,000	105%	144%	151%
	Perpendicular		....	1,060,000	1,190,000	1,370,000	112	115	129%
	Axial Shear		....	1,470	1,770	2,410	120%	136%	164%
	Direct Compression								
	Ultimate Stress								
	Parallel		....	7,050	8,000	10,500	113%	131%	149%
	Perpendicular		....	7,100	8,100	11,200	114	138	158
	Proportional Limit								
	Parallel		....	4,200	4,250	6,200	101%	146%	148%
	Perpendicular		....	4,550	4,500	5,500	99	122	121
	Modulus Elasticity								
	Parallel		....	1,370,000	1,410,000	1,920,000	113%	136%	140%
	Perpendicular		....	1,280,000	1,520,000	2,300,000	119	151	180
I	Average birch gain	1/48″	Shows Trend Only				132	103	136
II	Average birch gain	1/28″	Shows Trend Only				113	132	147

All plywood with alternate cross layers and Single Tego Bonded 300°F.—30 minutes per inch.

strength increments in plywood of the thinner veneers were most conspicuous between 500 and 1000 pounds pressures, while in the thicker veneers, the strength improvement was less in this range, but far greater in the 1000- to 1500-pound range. A logical explanation may be that with a higher resin content in the former, the density increased in the lower range; while in the latter, with less resin, the higher pressure range gave more significant results.

More complete information may confirm or modify this preliminary comparison of the two types of high-density plywood.

Effect of Moisture

The effect of immersion in water, or of severe weather exposure, on high-density plywood is far less serious than on normal plywood or solid wood. There will inevitably be some small degree of absorption, varying with the density. Wood is always more or less hydroscopic, until and unless all cavities are completely filled with substances that are unaffected by moisture. The extent to which high-density plywood will reabsorb water is dependent both on pressure and degree of resin impregnation, as well as on the size of the pieces exposed. It is desirable to use suitable protective coatings for extreme exposures, as is the case with all wood products. Since the specific gravity of wood substance, and of the types of phenolic resins used for adhesive purposes, is both approximately 1.35 to 1.45, it is apparent that high-density plywood at 1.30 and up, with a waterproof impregnant, affords almost no opportunity for the acquisition of water by soaking.

There are a number of medium-density plywood uses, where a certain amount of expansion under moisture exposure is a distinct advantage. An example is a plywood barrel stave, actually a laminated wood construction, which is pressed at about 500 pounds, with a specific gravity of approximate unity. When such a barrel is filled with water, the staves expand slightly, tightening the joints beyond the point of leakage. On subsequent emptying and drying of the barrel, the normal shrinkage does not occur, because the slightly expanded stave is still in the compression range, and will not shrink back to its minimum compressed size. In other words, compressed wood, in the lower pressure stages, on exposure to moisture, will tend to reassume its original dimension before compression, and this expansion is not reversible under subsequent drying, as is normal wood.

This characteristic of medium-density plywood and laminated wood is of distinct value in many other applications, such as many types of boat building and other marine uses.

Differential Density Constructions

Differential density plywood is a special type of veneer assembly in which one portion of the plywood unit may have a different density from the remainder. An illustration of such an application would be an aircraft propeller blank, where the end nearest the hub requires high density and tensile strength for adequate clamping. It is equally important that the end adjacent to the tip be as light in weight as possible to reduce the centrifugal forces. Such blanks are made of several layers, from ½ to 1 inch in thickness, each layer having the requisite differential density. These layers are glued together into a sturdy blank or block, which is machined to the shape of the blade. The construction of the layers is shown in the upper portion of Fig. VII. 4, in which there are twice as many sheets of veneer at one end as at the other. These shorter sheets may be of

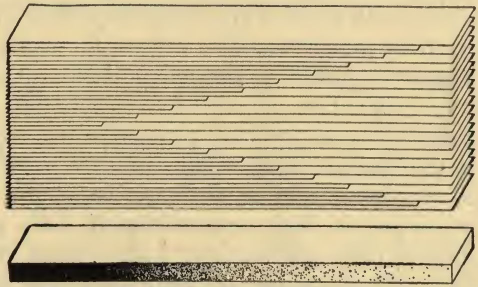


Fig. VII. 4—Differential density layer for propeller.
Above—assembly before pressing. *Below*—layer after pressing to uniform thickness.

any desired length to distribute the differential density as required by the stresses imposed in flight. They usually taper with more or less regularity, but sufficient length of uniformly high density is provided for hub clamping. It is a matter of design whether the density change from this hub shoulder to the tip is quickly reduced to the low-density condition for the balance of the blade, or whether it is reduced on a uniform gradient. The layers in such a propeller blank usually are made of laminated wood construction, i.e., mostly lengthwise laid veneers, and preferably without cross veneers for stabilization, strength and non-splitting qualities. This predominantly lengthwise arrangement preserves a maximum of tensile strength. If the veneers are 1/24 inch or thinner, and the step downs are well placed, no concentrated weakness will occur at the points of step down. Some prefer a construction in which each foreshortened veneer sheet tapers in thickness, but this is a costly process, and there is no evidence that it is necessary.

The technique of compressing and bonding this variable thickness assembly into a strip of uniform thickness requires metal bars for thickness control between the platens of the hot press, maintaining the platens in exact parallelism. Obviously, more pressure is exerted on the thick portion of the assembly, which is substantially compressed, than on the thin portion, where the volume of wood must be sufficient to give a good adhesive bond, with thickness reduction of the order of 10%, or less. Specific pressure in such a process must be computed on the area of the thickness control bars and the total area between them, although this is approximate at best. The gradient of differential density is shown by the depth of shading in the lower half of Fig. VII. 4. Phenolic resins are preferable for this work, either in film or liquid form.

When the layers have been pressed and properly tempered in an air-conditioned room, they are planed to provide a better gluing sur-

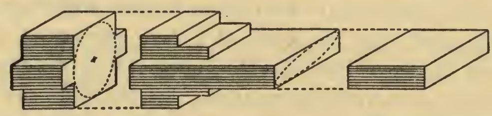


Fig. VII. 5—Differential density layers assembled into a propeller blank.

face (than the ironed surface from hot pressing), and glued together into a blank, of which one type is shown in Fig. VII. 5. This is then turned into the shape of a propeller blade, with proper clamping provision at the hub end. In many instances this hub end is bored for the insertion of a metal stud or core.

This propeller construction is only one type of differential density plywood, which can be easily grasped. While this differential density product is relatively new, and has enjoyed little commercial recognition, it is believed to have large possibilities. It meets the requirements in locations where the distributed strength characteristics of plywood are imperative, but where one or more points are subjected to extreme stresses.

Predetermined Plywood Strength

This ability to adjust plywood constructions according to anticipated stresses will become increasingly valuable to engineers and designers as further studies become available in this field. The product is of too recent development to have accumulated adequate data on the strength factors of the great variety of constructions that are possible.

This favorable change in plywood strength characteristics, through increase of density, is somewhat analogous to the alloying and heat

treatment of metals to improve their qualities, in which far more progress has been made than in plywood. It gives to woodworkers an opportunity to meet design requirements that are far beyond the range of normal wood or normal plywood.

Low-polymer Phenolic-resin Impregnation

A low-polymer type of phenol-formaldehyde resin, recently studied and described (1941) by the Forest Products Laboratory, gives promise of distinct improvement over the high-polymer resins used in the earlier impregnation processes. This low-polymer resin appears to migrate into the spongy walls of the wood cells, and thus to reduce water-absorptive capacity in that part of the wood structure where shrinking and swelling normally occur. Veneers can be impregnated green or dry, and the resin may be cured either with or without pressure. Under this type of impregnation the compression of the wood is distinctly greater than with other known impregnants. Hence, high-density plywood can be made at lower pressures than outlined in the preceding pages. This development is too recent to have received more than commercial recognition, but it offers distinct promise in the making of high-density plywood.

Lignified Wood

Another type of high-density plywood is in the experimental stage, impregnated with lignin that can be polymerized under simultaneous heat and pressure. Little is yet known of its physical characteristics, but they are probably similar to those of the resin impregnated plywood.

* * *

The author and publishers realize that the information presented on high-density plywood is elementary and far from adequate, but the data are the best available. Their defense for the presentation of only these fundamentals, if one is needed, is their earnest hope that it may encourage others to explore more fully this field of challenging opportunities and possibilities.

QUESTIONS

1. What is the relation between density and specific gravity?

2. Discuss normal plywood pressures.

3. Describe two methods of introducing phenolic resin into plywood, the film and the solution.

4. Why should high-density plywood, using a thermosetting, resin, require cooling before the release of pressure?

5. Describe the major variables involved in making high-density plywood.

6. What conclusions are to be drawn from the tests made on various thicknesses of veneer?

7. What differences in results are to be noted when using different species of veneer?

8. Under increasing pressures, do the strength factors increase faster than the amount of raw material required to maintain the product thickness?

9. In what pressure ranges is the strength improvement most conspicuous, when using 1/48-inch birch veneer?

10. Do wood species tend to lose their identity as the pressure increases and why?

11. Discuss the results when more than one thickness of Tego film is used.

12. What is the effect on the different strength factors when using more than one layer of film?

13. Discuss briefly the significance of tests on 1/48-inch birch as contrasted with those on 1/28-inch birch.

14. Outline the problem of moisture reabsorption into high-density plywood.

15. What is differential density plywood and how is it made?

16. Describe an airplane propeller so made.

17. Discuss the opportunity that is presented by the high-density plywood technique to predetermine plywood strengths for design purposes.

18. What is the analogy to the above in the metal field?

SECTION EIGHT

PLYWOOD IN INDUSTRY

INDUSTRIAL APPLICATIONS OF PLYWOOD

A reasonably complete enumeration of the various uses of plywood in industry would make a long list with many overlapping classifications. In order to illustrate the more important types of plywood utilization, several of the major applications will be described in some detail, with adequate cross references to similar adaptations in other industries.

There are three principal methods under which plywood is used in the manufacturing and construction trades, and they are somewhat interlocking in nature.

One major use is plywood in standard sizes and construction which are termed **stock panels** (page 86). These are made at a plywood factory, warehoused at central distributing points, and used extensively by the building trades. On the other hand, some of these stock panels are cut down and remanufactured into furniture, boats, cabinets, aircraft, and the like. Essentially, however, these stock panels are an established line of merchandise.

Another method of plywood utilization is that of **custom-made** plywood, manufactured at the type of plywood factory mentioned above, but designed to the customer's specifications. This custom-made plywood is shipped to the assembly plant, where it is further manufactured and combined into furniture, cabinets, radio and phonograph items, and the like.

The third major method is that of making the complete product under a single roof, from the veneers to the finished unit. Typical examples would be molded trays of the "Toastmaster" type (page 278), grand piano rims (page 28), or a molded boat hull, fabricated from veneer to the finished boat. This might be termed a highly **specialized** type of plywood construction, where the ultimate requirements are such as to make it inadvisable, due to quantity, quality, complexity, or interrelation with other solid-wood parts, to permit the plywood to be made at an independent plywood factory.

There are various combinations of these methods that have been developed under the stress of modern industrial demands.

The industrial applications that follow are grouped according to the more important industries of consequence, but the list is in no sense complete. New adaptations are constantly in progress, and while some are rather daringly suggested by the author, there are many more in the inevitable throes of development. The arrangement which follows is alphabetical, without reference to importance.

AIRCRAFT CONSTRUCTION

Historical Background

The design requirements of early aircraft, in the first decades of the present century, were the first compelling urge toward the scientific development of the stength/weight advantages that have become so characteristic of well-designed plywood. If fact, the term **plywood** did not come into general use until about that time. With its many advantages in aircraft construction, there were a few limitations in plywood utilization that were recognized as serious handicaps in the era of the first World War.

One of the disadvantages that has been imputed to plywood, but quite incorrectly, was its tendency toward inflammability. It is perfectly apparent that the major hazard in flight is the gasoline fuel. If this becomes ignited, at any point or from any cause, it matters little whether the plane is made of fabric, plywood, wood or metal; the results are equally disastrous. Experience has changed opinion on this point, due partly to better safeguards against fire, so that the possible but over-emphasized fire risk is no longer considered an unfavorable factor in the use of plywood as an aircraft material.

The other major limitation to wood and plywood construction, in this early period, was the character of the adhesives used in making the plywood and in assembling the wood and plywood parts. The adage of the weakest link in the chain was a singularly accurate analogy to the quality of the adhesive used in the plywood.

In order to get perspective and to evaluate intelligently the excellent plywood adhesives of the present time, it is important to outline briefly the background of the adhesives that were available at the time of World War I. At that period, **casein** (made from the curds of soured milk) and **albumin** (a dried blood product coagulated under heat) were considered the most durable adhesives for aircraft construction. Neither would withstand even an elementary mold and fungi test; in fact, under suitable conditions, both encouraged such parasitic growths. Casein plywood,

bonded cold and tested dry, gave excellent bonds, and the addition of lime, up to 15%, improved its water resistance, but made it abrasive on edge tools. At best its resistance to continuous soaking and to alternate wet and dry tests was relatively low. It failed quickly in boiling water. Albumin plywood, hot pressed, possessed unusual water resistance, in fact could be soaked for many days, and would resist several cycles of wet and dry tests. It was not abrasive on tools, but it was found to deteriorate seriously with age.

In spite of these limitations plywood continued to be used extensively in aircraft construction during the 1920's, but it was gradually displaced by metal. This was due, to a considerable extent, to the better co-operation between metal manufacturers and the aircraft industry, than was the case with the plywood makers. The metal advocates, evidently, were more interested in research and more eager to develop the necessary scientific strength data than were the plywood group. Another retarding influence was the almost infinite variety of plywood constructions, which made standardization and classification exceedingly difficult.

Soon after 1930, with the rapid growth of the plastic industry, resin adhesives began to attract the attention of the plywood industry. At first the phenol-formaldehyde resin was the only one available and that in film form on an import basis. While only a few hot presses were available, the hot-pressed resin plywood gave convincing evidence of far better durability than either casein or albumin, but the high import cost retarded the growth of the resin adhesive program.

By 1935 the demand for phenolic-resin film was sufficiently urgent to justify domestic manufacture, which soon reduced the price to about half that of the imported supply, a typical American experience. With this impetus, and the excellent durability characteristics that were found in Tego bonded plywood, the aircraft industry began to renew its interest in plywood. These improved durability factors were:

1. Complete waterproofness, adhesive insoluble until wood decays.
   High resistance to bacterial growth.
   Boil-proofness, facilitating bending and curving after steaming.

The liquid phenolics, developed several years after the films, were also found to possess the same durability characteristics. This development of phenolic adhesives removed the principal objections to the use of plywood in aircraft.

Beginning about 1940, a new phase developed in the rivalry between the use of metal and wood in aircraft construction. The combined demands of world defense and commercial aviation were grow-

ing faster than the metal industries could expand, and plywood, almost over night, became doubly valuable, first for its own qualities, and second because it could be used in many plane parts to relieve the threatening shortage of metals.

Design Technique

There are fundamental differences in design requirements between wood and metal in aircraft construction. Wood has bulk and stiffness with high strength/weight ratios. Wood surfaces can be glued together. These facts give substance to the belief that molded plywood parts, with light, but strong arch effects will be important factors in the aircraft of the future. Metal parts may be thinner and smaller for a given strength, but their attachment methods, by welding and riveting, are much more localized than the gluing together of wood parts over substantial areas. Obviously, the mere substitution of plywood for sheet metal, or vice versa, without fundamental design changes, may lead to serious difficulties. Maximum advantages for each material are only obtainable by intelligent utilization of wood experience on its designs and of metal knowledge on metal constructions.

Laminated Spars

The term laminated refers to the parallel grains of the adjacent layers, while regular plywood has alternately crossed grains. A solid single piece of wood, of the same size and species, is less desirable for aircraft than a laminated piece of the same dimensions, since the fabrication permits balancing or bracing grain effects, reinforcement of adjacent layers, freedom from checking and more uniform moisture content. While spars for small "cub" planes are often of solid wood, there is a distinct tendency to make them of laminated layers of sawn or sliced veneer. In general these spars are approximately 1 by 6 inches at the large end, tapered toward the small end, and in solid lumber seldom are available over 20 feet long. If laminated from ⅛-inch spruce, the lengths can be increased to almost any desired point by staggering and scarfing the splices as shown in Fig. VIII. 1. With a properly applied resin adhesive the quality of the laminate

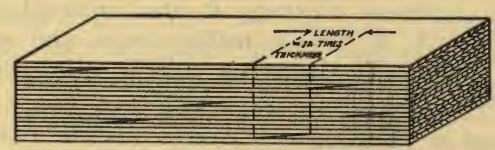


Fig. VIII. 1—Laminated spars of Sitka spruce veneers.

Note: Individual layers are scarfed (L = 12 T) to utilize shorter sheets of veneer; scarfs are staggered for strength distribution.

will be superior to solid spruce while the cost will not be out of line.

In larger types of trainer planes spars may be made either of overlaid ½-inch layers of solid wood or by aggregating pieces of laminated constructions as shown in Fig. VIII. 1. These large spars are often built up to 3-inch to 4-inch thickness at the fuselage ends, for reinforcing, while the layers taper or leaf out toward the outer ends. Some spars are made of hollow-beam construction toward the outer end, with thin diagonal plywood covering.

Urea resin adhesives are suitable for all spar joints, while phenolic resins are preferable in the plywood used for covering. The use of hot-pressed resin adhesives on spar constructions is not advised, since it is desirable to maintain the moisture content of spars around 15%, to insure maximum resiliency. The chemical-reactive resins, however, are very satisfactory for this purpose. Electrostatic heat (pages 182-6) may prove to be the best process for curing resin bonds in spruce spars.

Plywood Ribs and Gussets

There is a wide range of constructions and designs possible here. It should be kept in mind that, under column types of loading, solid wood often has a favorable strength/weight ratio over plywood, while for distributed strength and non-splitting qualities plywood is far superior to solid wood.

Assembly jigs are often provided to make a dozen or more ribs of a certain kind or size. Pegs or pins between the top and bottom members of the jig will keep the successive ribs in vertical alignment, and adequate pressure can be applied to the entire jig charge by simple screw clamps. The jig and its contents can be placed in an oven to accelerate the bonding of the adhesive.

If the edges of the ribs are to be used for bonding a plywood skin covering, it is often important to provide extra edge width for secure anchorage of the skin to the framework. A properly designed "T" section will meet this requirement.

As in the case of the spar constructions, urea resins are best for assembly joints, while phenolic resins are to be preferred for joints in the plywood. In the case of such small areas as are involved in rib assemblies, sufficient pressure is often attainable by properly designed nails, with or without nailing strips, and sometimes by strong spring clamps. The important point is to bring surfaces into intimate contact.

Skin Coverings of Plywood

One of the fundamental advantages of plywood is its stiffness/weight factor, which can be simply illustrated as follows: Aluminum

sheets have a specific gravity of 2.8 approximately, while spruce plywood has a corresponding characteristic of .5 to .6. Hence for an equal weight, plywood can be four to five times as thick, or for equal thickness, plywood is correspondingly lighter. Plywood can be glued to the ribs and spars, while metals have to be riveted, a distinct disadvantage. The springiness of plywood renders it less easily damaged and if damaged it is much simpler to repair.

Certain combinations of plywood thickness and curvature can be bent cold and dry. If the curve is too severe, Tego-bonded plywood can be rendered ductile by steaming and then bent and dried over either a single or double form, which may be heated. Sometimes rather sharp curves are facilitated by bending at 45° with the face of the plywood, rather than parallel to any layer within the plywood. It is becoming increasingly apparent that thicker skin coverings, at such locations as leading edges, may permit the elimination of a substantial number of ribs, with consequent reductions in time, weight and cost. In some cases these thicker plywood surfaces may consist of several layers of 2-ply, which can be steamed, bent and stressed far more than single layers of veneer, without rupture.

The assembly of skin coverings, as for a wing, on plywood and wood framework, can often be done with flexible-bag pressures with rather simple forms, as is described on pages 186-90. As the actual contact area is only a small proportion of the total surface, bag pressures need not be high, and both heat and pressure can be applied simultaneously. Another method of applying heat is to use the electrodes from a high-frequency electrostatic field, as outlined on pages 182-6.

Since the plywood skin is relatively thin, the use of hardwood nailing strips is advised, whenever nails are employed as a pressure technique. In pressure application on sufficiently convex surfaces, metal straps, with tighteners, can be employed.

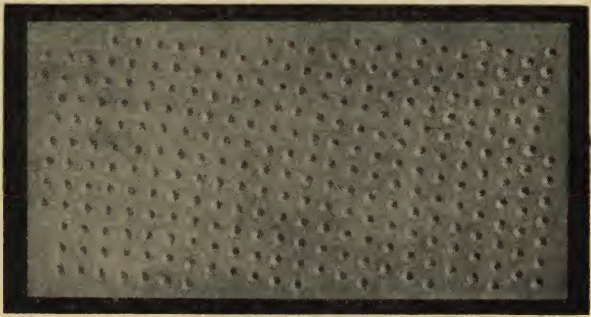
High-density Plywood Reinforcing Plates

Solid lumber, such as the spruce used in spars, splits easily and has very low bolt-holding power. Hence, spruce spars require sturdy reinforcement where they are attached to the fuselage or landing gear. While this is often done with metal plates, it is possible to get very excellent results from the use of reinforcing plates of high-density plywood, of which the strength characteristics are given in Table VII. 3, page 203. It is to be noted that the resistance to shear is increased some seven fold, as between solid wood and plywood pressed at 1000 or 1500 pounds specific pressure. While both solid maple and normal pressed plywood (200 pounds p.s.i.)

are used for such reinforcing, the denser product offers distinct advantages in the weight/shear ratio, i.e. where shear resistance increases some 700%, the specific gravity or weight only increases 116%

One important factor in using high-density plywood for reinforcing plates is to have the surface adjacent to the softwood sufficiently roughened so that the bond will be both mechanical and adhesive. A simple way to accomplish this is to have one face of the high-density plywood molded (as it is cured or bonded) into a metal die or matrix with recesses, that will become projections above the surface of the plywood, as is shown in Fig. VIII. 2. There are a number of types of roughened surfaces that can be molded on the plywood surfaces as it is made. Such projections on the plywood, or roughened surfaces, can be pressed into the spruce by the bolts and will result in a mechanical grip of unusual strength.

While the spar is the most obvious place on which to use high-density plywood reinforcing plates, with mechanical interlocking into the wood surfaces, there may be other locations where such strength developments can be utilized to definite advantage.



Courtesy, Armstrong Cork Co.

Fig. VIII. 2—High-density plywood reinforcing plate.
Bonded at 3000 lb. sq. in., with extra resin for embossments.

Propeller Constructions

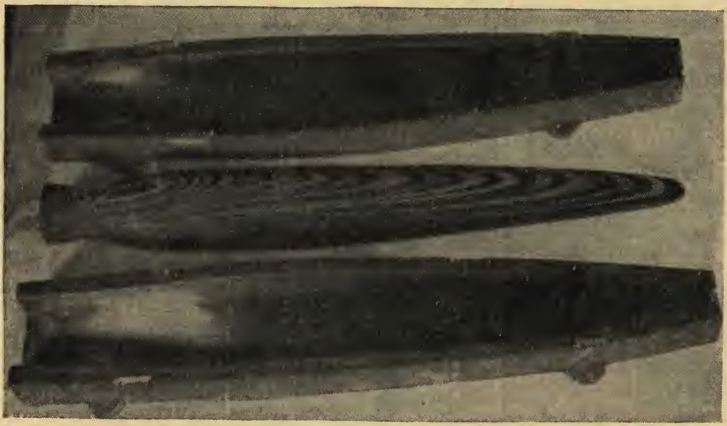
Progress in the propeller field is rapid, and it would be venturesome to predict the extent to which wood and plywood, with its newly developed attributes of high density, may enter the field of propeller design. At the time this is being written (1941), information is filtering in from Europe that plywood propeller constructions are being extensively used on the fighting front.

At the present time many, if not most, of the double-blade straight propellers for "cub" planes are laminated wood, built up out of ¾-inch birch, mahogany or walnut lumber, and this type of construction seems well established.

As the service becomes more exacting on larger planes of the various trainer types, there is a tendency to use two single blades, mounted on a straight line, in metal hubs provided with clamps that permit adjustment of pitch, on the ground, but are in fixed position during flight. Here plywood fits the requirements adequately, and the blanks may be made with high density at the hub end and low at the tip, as is outlined below for larger sizes.

Large propeller blades have been made of wood, using strips ½-inch thick, that are very dense "Jicwood" or "Pregwood" at the hub end. This dense portion is scarfed onto spruce for lightness toward the tip end, where gripping power is not essential. These laminae are built up into suitable blanks for blades that may approach 12 inches in width and 10 feet in length.

A type of propeller construction that is finding increasing favor is made from a blank, built up of several layers of plywood (½ to 1 inch thick), suitably dimensioned to reduce the labor of turning to shape, and so arranged that the layers of plywood are as nearly as possible parallel to the flat portion of the blade. An example is shown in Fig. VII. 5, with final shape indicated in dotted lines. Some authorities prefer variable density (high at the hub and low at the



Courtesy, Robert Decat

Fig. VIII. 3—Molded plywood propeller blade.

Each layer cut to approximate size before bonding, impregnated with phenolic resin, and pressed in a pair of metal dies, thus eliminating most of the expensive machine turning.

tip) plywood, see page 210, with thicker blade sections, while others advocate uniform, high-density plywood, with thinner blade sections.

There are also differences in the technique of using cross layers of veneer in the plywood propeller blanks, to secure the non-splitting quality and the dimensional stability that plywood construction provides. Most of the wood layers in propellers are lengthwise, i.e., essentially a laminated wood construction.

Another method of plywood construction is to cut each layer of veneer to its approximate final size and shape, then lay them together in sequence, with adhesive, in a pair of metal molds, which will press the aggregate assembly into slightly over its final size and shape, as is shown in Fig. VIII. 3. In these molds, the layers are twisted, in the bonding process, so that the central layers of veneer will follow the spiral of the blade. This method of construction largely eliminates the turning of the blade to shape, since only a thin cut needs to be removed to smooth off the surfaces of the blade.

Most of these propeller constructions are protected by U. S. and foreign patents, and prospective users should investigate carefully before proceeding.

Developments in wood and plywood propeller design are likely to become increasingly important in the near future.

Other Plywood Uses

There are many other less conspicuous uses of plywood in aircraft constructions, where the qualities and characteristics of plywood give it distinct value over those of other materials.

The electrical insulating qualities and workability of plywood make it almost ideal for **instrument boards.**

Plywood floors find wide use, two types of special constructions being shown in Fig. VIII. 4. The upper is essentially a combined and integral floor and joist construction, that may be varied widely in structural details, but is bonded rigidly together with a resin adhesive, and affords surprising stiffness/weight factors. The

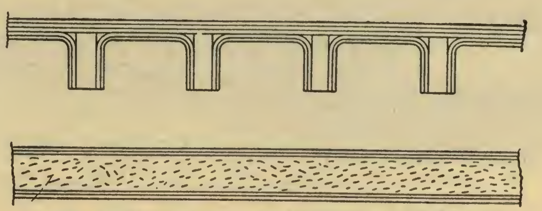


Fig. VIII. 4—Aircraft floors of plywood.
Upper—ribbed plywood, of which there are many types. *Lower*—plywood with balsawood or cork core.

lower part of the illustration shows a 5-ply construction, with balsa-wood (or aggregated cork) as a center layer. The outside veneer layers will carry the bulk of the stresses, while the center layer, although of a low strength material, is exposed to a minimum of stresses. This bears some resemblance to hollow-beam construction.

Both of the constructions shown in the illustration would probably require two- or three-stage adhesive bonding, the first in flat plywood, hot pressed, under adequate pressures, that might be too great for the subsequent operations

Portable, semi-portable and built-in equipment, such as **chairs, seats, tables, partitions, berths, compartment enclosures** and the like, can preferably be made of flat or curved plywood. Surface finishes may be natural, colored, fabric covered or metal lined, as may be required.

Plywood is especially adapted to the building of **scale models** for design study and wind tunnel tests. The working of plywood is far simpler than that of metal, and the resulting product is stronger than cloth, paper or papier-mâché.

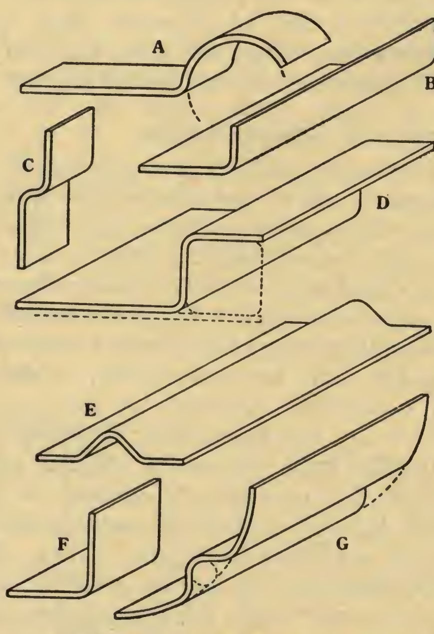


Fig. VIII. 5—Plywood clips.

A—flat surface to large, round rod. *B*—angle clips. *C*—offset straight clips. *D*—flat surface to square frame member. *E*—flat surface to small, round rod. *F*—angle clips. *G*—curved surface to small, round rod.

The high-density types of plywood are an excellent material out of which to shape pairs of forming dies for thin sheet metal parts. This material is easily shaped by woodworkers with woodworking machines and hand tools, and the cost of dies may thus be far less than when made of metal. Such dies have long service life and can easily be reshaped for slight changes in design.

Plywood patterns for metal sheets and for contour testing are light in weight and inexpensively made. They are easily marked, and practically permanent in shape and size.

One of the newer developments is a plywood clip or fastener to join plywood sheets to wood or metal frame pieces, as shown in Fig. VIII. 5. These clips can be made of various thicknesses of veneer, bent to a wide variety of shapes, and pressed at high specific pressures to attain maximum strength. They have the distinct advantage of permitting attachment of adhesives over their whole area, as well as by screws and bolts, where metal clips have limited attachment areas, either by riveting or spot welding. The proper pressure for attaching plywood clips can be secured and maintained by screws or bolts that can be removed if desired.

The minor incidental uses of plywood, other than those mentioned, are too numerous to list, and often have an importance far greater than their size or appearance would suggest.

Molded Airplanes and Sub-assemblies

There have been much publicity and propaganda on the subject of plastic airplanes, a rather inaccurate description, as the planes so far made have been molded plywood with resin adhesives and finishes. There may be justification, from a sales standpoint, in associating the molded airplane with the rapidly growing plastic industry which has been termed the phenomenon of modern research and industrial development. From a technical or scientific standpoint, the use of the term is not easy to defend. The principles involved in molding plywood are old, and the only new and novel features are the methods of applying the pressure as well as the unusually large size of the molded unit. The fundamental principle is that of using the inflated or deflated flexible bag as one of the halves of a pair of molding dies. There is not only the saving in matching up a pair of dies, where the intermediate distance between the halves must be very accurately determined, but in some cases the use of dies is wholly eliminated. Most of the pressure applications in the plywood industry have been in a single direction, while flexible-bag pressure is of the order of fluid pressure, and at substantially right angles to any

surface that is under pressure. Natural or artificial rubber bags are used, with fabric linings, and they must be designed for repeated heat applications without serious deterioration. It is the flexible quality of the bag that is important, rather than any extensibility or stretch that it may have. Among the better known of the processes employing this flexible-bag principle are Duramold, Vidal, and Timm.

A **monocoque** construction is one where the stressed shell shape provides the essential elements of strength, as the shell of an egg. There are many minor and major departures from this principle, and these modifications, with the addition of more or less internal framework, are called, somewhat loosely, **semi-monocoque** construction. Molded plywood has been considered one of the most efficient types of monocoque construction, with excellent strength/weight ratios, but stiffening and bracing members are often used.

Several of the more important applications of these flexible-bag pressure principles have been quite fully described on pages 186-90. The processes have been used in the airplane industry for several years and a number of molded planes have been completed and flown successfully.

A typical example of a molded half fuselage is shown in Fig. VIII. 6. The rings (plywood) and the longerons (wood strips) constitute the framework (A) that is usually placed in slots or recesses in the inside mold or die. The strips of veneer comprising the inner layer (B) are properly tapered so that they will fit close together, without laps or gaps. The central layer (C) consists of veneer strips going around the fuselage, like hoops on a barrel, similarly fitted. The outer layer (D) is substantially the same as the inner, except that the outer veneer joints should be staggered with regard to the inner joints. Adhesive is sprayed or spread on all surfaces that make contact, and the entire assembly held together, temporarily, by tape, brads, bands, wire or other fasteners until the pressure can be

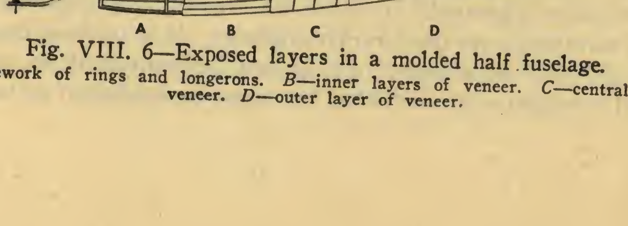


Fig. VIII. 6—Exposed layers in a molded half fuselage.
A—framework of rings and longerons. *B*—inner layers of veneer. *C*—central layer of veneer. *D*—outer layer of veneer.

applied. The two halves are usually glued together, with a splicing plate or longeron, to reinforce the scarfed plywood joint at the top and bottom. The rings may be similarly spliced.

At the present time (1941), however, there has been little actual volume production, except on parts and sub-assemblies. Current developments are proceeding rapidly and the results appear to be very encouraging. The mechanical adaptations are not difficult, but the chief obstacle to broader use is the lack of standardization in aircraft design. There is no reason why these rubber-bag methods should not find extensive use in airplane sub-assemblies, when and if some standardization becomes well established. Whether the processes will be adapted to large units like fuselage halves or complete planes is a problem that time and experience will reveal. The excellent weight/strength ratios of plywood and the smooth exteriors, without rivets, both add to the air effectiveness of such types of planes.

The resin adhesives are admirably adapted to these molded plane designs. If sufficient heat and pressure are attainable the phenolic liquid resins are preferable, while the urea resins will give good results if conditions are unfavorable for the use of phenolics.

Physical Properties of Plywood

Fundamental data on the strength characteristics of solid wood are well established. It should be noted that the behavior of wood under stress loadings is sometimes quite different from that of metals, since wood is relatively non-homogeneous, while most metals are quite homogeneous. Most technical information on the strength of materials has been in the metal field and has been based on the behavior of metals. Since wood reacts quite differently from metal in some respects, it is not always possible to compare consistently the performance of wood and metal. As a consequence, some of the desirable qualities of wood have not been adequately recognized.

Plywood, while depending for its strength characteristics on the strength elements of the various sheets of veneer of which it is composed, still presents several new qualities of distinct value. In addition there are many principles of design and types of construction in plywood that, under intelligent application, can be utilized to secure special strength requirements that far exceed the normal in either wood or plywood. It is for this reason that plywood offers unusual advantages to the aircraft engineer. It is obvious that these special plywood advantages can seldom be expressed in standard tables of strength characteristics, but must be evaluated in terms of

understanding in the use of plywood, and from experience in its application.

Engineering data on veneer and plywood strength characteristics are given on pages 311 to 322. Interpretations of tables given in *Strength of Aircraft Elements, ANC-5* are given in the *Journal of the Aeronautical Sciences* for March, 1941. Other strength data will be found in many of the references cited in the Bibliography.

BARRELS AND COOPERAGE

The adaptability of veneer and plywood to curved shapes has long been recognized. The manufacture of barrels and cylindrical containers would appear to offer a very fertile field for its use. However, the actual achievements in this line have been relatively few, due partly to cost, as compared with metal drums; partly to the bilge shape that imposed serious mechanical difficulties on a material like plywood that had very little "stretch" potentialities; and perhaps still more to the traditional trade of the cooper, in which the conventional stave and hoop construction persisted, in spite of the large amount of trained handwork that was demanded.

During the last decade, Europe has made some progress along this line, and developments are beginning to appear in America.

Cylindrical drums, not of the bilge shape, are described elsewhere, pages 252-3.

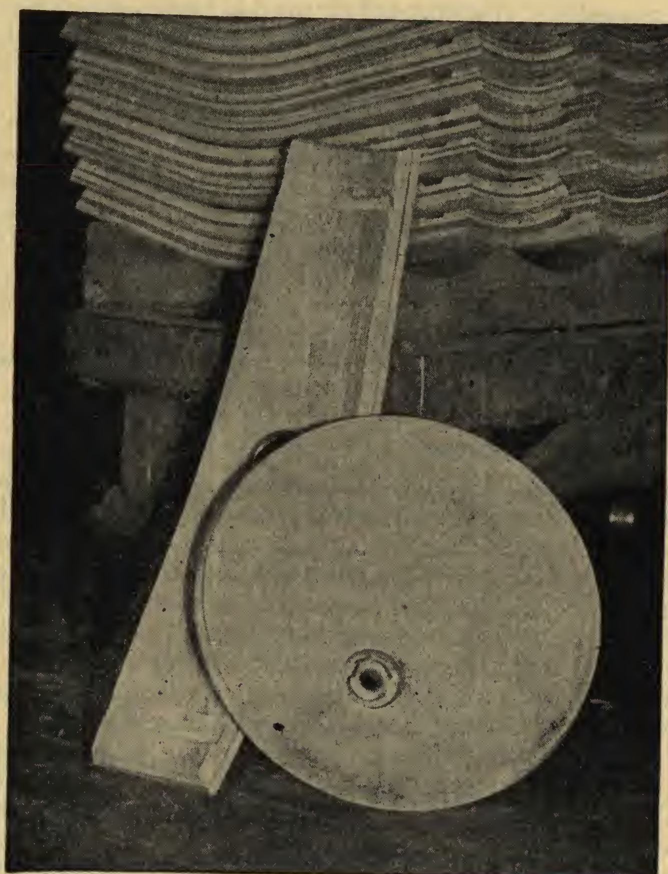
Beer Barrels of Plywood

The conventional barrel (tight cooperage) was a triumph of the cooper's art. Solid white oak staves were cut on a cylindrical saw, steamed and bent to make the bilge, shaved to a taper endwise and sidewise, crozed (grooved for the head), and trimmed, to mention only a few of the principal operations in barrel making. These staves, of random widths, were then carefully and painstakingly fitted together into a complete barrel and the heads inserted. These progressive steps in barrel-making were fascinating developments of an age-old trade, cooperage, in which the training was handed down from father to son. Skill and long experience were necessary to make a first-class cooper, and every barrel was practically custom-made. The resulting barrel was good, but it had some serious limitations.

The growing shortage of white oak timber and the tendency of the bent staves to break on the outside of the bilge, under hard service, combined with other lesser causes, forced a study of plywood to find, if possible, an improved construction, more in the modern

tempo of mass production, and emphasizing mechanical precision more than individual experience and skill.

It proved to be an opportunity for the use of the preformed plywood technique, in which the layers of veneer were pressed, under heat, with a resin adhesive, into the final compound curvature required in the finished barrel. Oak was used for the outer and inner layers, since white oak was everywhere accepted as the best barrel wood. The concealed center layers could be of other species. It was found that the veneer layers were best laid lengthwise, in a laminated, rather than a strictly plywood construction. Instead of a



Courtesy, Verdi Bros. Cooperage Co.

Fig. VIII. 7—Finished plywood head and laminated staves.
Note the unusual width of the stave.

barrel of 15 to 17 narrow random width staves which were made as wide as solid staves could be successfully bent, this laminated construction permitted a standard width stave, and only 8 or 9 per barrel. This reduced the stave joints by one half, and correspondingly reduced the chance of leakage. Standard widths shortened the time of assembly. Since the ⅛-inch veneers bent easily under combined heat and pressure, the hazard of wood rupture outside the bilge was entirely eliminated. Standard preformed staves could be more accurately machined to size, since every cut was an exact mathematical plane through the central axis of the barrel, and even new barrels showed little leakage. This laminated construction ex-

Courtesy, Verdi Bros. Cooperage Co. and Camfield Mfg. Co.

Fig. VIII. 8—Hot press for laminated staves.
Note press has commenced to close from the bottom.

panded slightly when wet, but did not shrink when again dried, so that a dry plywood barrel was a tight barrel, far different from the older type of solid stave barrel.

The heads were normal cross-laid plywood, crowned inward, to resist internal pressures. The former jointing and dowelling of the

solid lumber heads were entirely eliminated, and with them, another source of possible leakage. A factory truck load of standard width laminated staves and a plywood barrel head are shown in Fig. VIII. 7, ready to assemble.

In the early stages of this development, every conceivable test was made to eliminate any possible defects, and to insure a better and more durable barrel than had before been possible. The adhesive used was the phenolic-resin film, Tego, which was found to have no effect whatever on the flavor of the beer, and produced a bond stronger than the wood.

The staves and heads were formed and bonded in pairs of steel dies, in the press shown in Fig. VIII. 8. Usually 11 plies of veneer were used in both.

This barrel development is a typical example of the adaptation of the new plywood processes to an old standardized product. The result is a better and more durable barrel, and an adequate remedy for the threatened shortage of white oak timber. Since some 85,000 plywood beer barrels were made from January, 1940 to May, 1941, by this new process, it can be considered as a thoroughly proven one.

There is little to report in the adoption of these plywood processes for other types of barrels for holding liquids.

BOATS AND SHIPS

Early Plywood Developments

The earliest known developments in watercraft, made of plywood, undoubtedly occurred in Ludington, Michigan, around 1912, under the supervision of Henry L. Haskell, an early pioneer in the use of blood-albumin adhesives. He undertook the manufacture of canoes, assembling layers of veneers into plywood, between pairs of forms of metal and concrete, coagulating the blood adhesive by steam cavities in the metal half of the forms. The venture was hardly a commercial success, due largely to the fact that Haskell's interests were taken over by a new company in Grand Rapids, which became the Haskelite Company, headed by the late George R. Meyercord, who had one of the most fertile minds that had then or has since appeared in the plywood field. The Haskelite Company was soon engrossed in the new and rapidly expanding aircraft industry, under the impetus of World War I, and little attention was given to plywood canoes.

While blood albumin was reasonably waterproof, it did not develop into an adhesive of wide utility, and consequently little ply-

wood was used in boat construction until the advent of resin adhesives early in the 1930 decade. The records show that renewed interest became evident about 1932, when Tego resin film began to be available on an import basis. However, the amount of plywood used in boats did not begin to become impressive until about 1938, when Tego-bonded plywood had attained a very considerable distribution through the activities of the United States Plywood Corporation, to whom is due much credit for intelligent and constructive merchandising in the boat-building field. This was due partly to the large number of hot presses that had been installed, the availability of American-made resin adhesives, and also to the favorable experience that had been gained from the actual use of hot-press resin-bonded plywood under severe conditions of exposure.

Sheet Plywood for Hulls

The availability of large, flat sheets of waterproof and reasonably flexible plywood paved the way for its use in small boats, at first of the flat-bottom types, such as dinghies, tenders, row boats, and even small sailboats. In these constructions plywood could be used to cover relatively large areas with few joints, the cross layers in the plywood reduced the splitting tendencies and improved screw holding qualities, the negligible shrink and swell practically eliminated the caulking, and the distributed strength of the plywood permitted the use of thinner and lighter material than could be used in conventional boat constructions with solid lumber. Since normal boat framing is designed to provide the necessary strength at right angles to the hull planking, the use of plywood, with its cross strength, greatly reduced the framing required, both in spacing and sizes. This, in turn, provided more inboard space. The use of plywood was adapted equally to the unskilled amateur boat builder or to the experienced professional.

As experience developed it was found that larger and more complicated hulls could be built of plywood, using long strips that could be considerably wider and more flexible than solid wood. Strips could be scarfed together endwise for requirements beyond the standard available lengths. Two layers of plywood could be used on a hull, with staggered joints, to take advantage of the flexibility of the plywood. When these plywood strips were properly tapered, much could be done in the direction of compound curvature.

Larger and larger hulls, of more and more intricate design, are being built, and it would be unsafe to predict, from present limited experience, how large boats can be made successfully of plywood sheets or strips. For scarf jointing see pages 190-1.

Plywood for Boat Interiors

Even before the days of waterproof resin adhesives, plywood had been used for interior partitions, built-in equipment, cabinets and furniture for large ocean-going and coastwise vessels. Casein glue was fairly satisfactory in such protected locations, especially with adequate surface coatings. Some of the decorative plywood used in such interiors rivaled that of the finest and best architecturally designed buildings.

The catastrophe of the Morro Castle, off the New Jersey coast in 1934, gave undue prominence to the fact that plywood, under severe conditions, would burn slowly, although more like a pad of paper than a single sheet. As a consequence, the safety requirements of partitions and bulkheads in passenger carrying vessels were stiffened. The new code required an inner or central plywood layer of some non-combustible material, of which "Marinite" by Johns-Manville was a type. This is an asbestos sheet, about ⅝ inch thick, much lighter in weight than the standard asbestos, and of sufficient

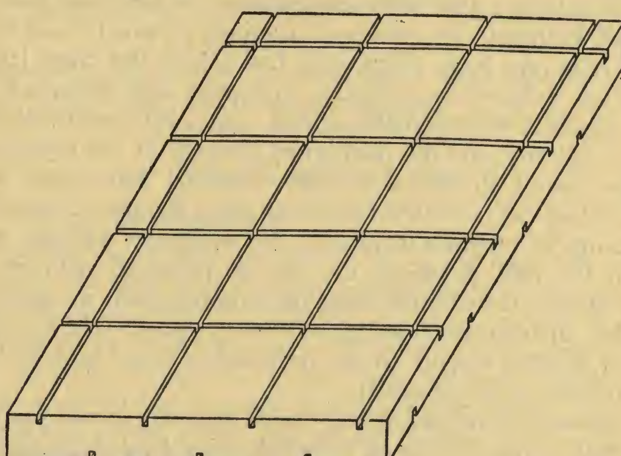


Fig. VIII. 9—Asbestos core for ship partitions of plywood. Proportions exaggerated for clarity. Saw slots are to permit the escape of steam in hot pressing.

toughness to handle without breaking at about 15% moisture content. It served as an excellent core or center for 5-ply constructions. This relatively high moisture content made it a difficult material to handle in hot-press operations. A method was eventually developed to slot both surfaces, as shown in Fig. VIII. 9, so as to provide vents for the escape of steam that develops in hot pressing. These saw cut

slots need only be 1/16 inch wide by ⅛ inch deep, cut at random across both surfaces of the asbestos, and not more than 12 inches apart. Such narrow slots will not show through the crossbanding and veneer faces. The reinforcing effect of these outer veneer layers results in a strong and sturdy plywood. This asbestos board used for plywood cores is slightly abrasive, but can be cut on ordinary woodworking machinery with special cutters. It can be bored, drilled, bolted and screwed like standard plywood.

Plywood for built-in equipment and ship furniture has been used for years, originally glued with casein, but more recently with resin adhesives. This marks a distant step forward in durability.

Superstructures on Small Boats

Plywood, now that it is available in thoroughly waterproof types, has greatly simplified the construction of the superstructure and adjacent parts of small pleasure boats. Instead of many narrow parts of solid lumber, that are not easy to bend and that inevitably develop a number of objectionable cracks, plywood can be obtained in strips, long, narrow and thin, for easy bending in coamings, or wide and flexible for decking, awnings and roofing, or sturdy enough, when attached to a suitable frame, for hatches and doors. In fact, the strength and flexing characteristics of plywood make it adaptable to a large part of the housings on small boats. If the curvature is too great for plywood of the required thickness, two layers can be used, gluing the layers together in curved forms.

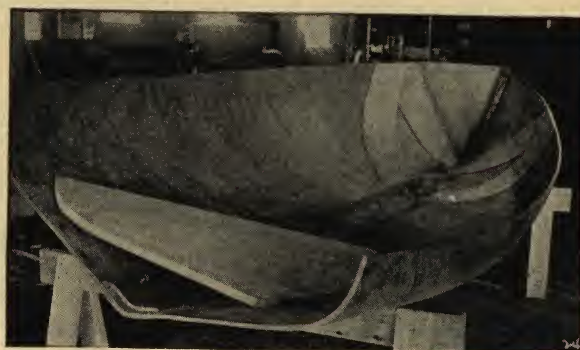
Plywood Bulkheads

Many of the moderate sized boats, up to 70 feet long, required for high speed, scout and patrol uses in the defense program, are equipped with a series of double bulkheads, so that the boat is practically non-sinkable, unless a considerable number of the compartments, between the bulkheads, are seriously damaged. These bulkheads are made of hot-pressed phenolic resin-bonded plywood sheets, strongly glued and screwed to both sides of intermediate frames, which also serve as the ribs of the boat. Plywood is far more leakproof, in this design, than any solid wood could be, and much lighter in weight, less corrosive, and lower in cost than any metal.

Molded Plywood for Hulls

So far the utilization of plywood in watercraft has been confined to the types of plywood that are made in flat sheets in hot presses with resin adhesives. There is a very definite limit to the extent of curvature that can be secured by this process.

Within a comparatively short time, the molding processes, with flexible-bag pressure, have been adapted to small boat construction with conspicuous success. An example of a two-piece molded plywood hull for a small boat is shown in Fig. VIII. 10. It is to be noted that the conventional ribs and keel are missing, but without sacrifice in strength. In fact, these frame members served largely as joints and stiffeners, and were not so efficient in this regard as



Courtesy, United States Plywood Corp.

Fig. VIII. 10—Two-piece molded plywood hull.

the shell or monocoque construction shown in the illustration. Such molded hulls can be made by several of the flexible-bag techniques that are described and illustrated on pages 186 to 190. Just how large hulls can be made economically by this process is not yet clear. Experience has indicated that it is entirely practical on boats up to 20-foot lengths, and it is believed that much larger boats will eventually be made by this process.

Some boat builders use single layers of veneer in this molding process, assembling sufficient layers to give the desired rigidity and strength. Others prefer using thin sheets of plywood, bonded flat, either 2-ply or 3-ply, cutting the same to proper shape, so that all edges will make close joints without overlapping. The resin adhesive has been applied during the assembling, and is cured under flexible-bag pressure, much as described above for molded hulls made of single-ply veneer.

One method in successful use is to apply several layers of plywood as large as a half hull, cutting out proper "V" openings toward the bow and the stern, staggering these "V" cutouts so that all joints will be strongly lapped. These are placed over a male form, with

resin adhesives in each surface joint. The pieces are held in approximate position by temporary fasteners, until adequately bonded under bag pressure. Ribs, stiffeners, keel, and gunwales, if required, may be recessed in the form, so that the shell of the hull will be bonded to them in the single bag pressing operation.

There are many methods advocated for this work, but the development is too recent to permit conclusions as to which is the best method. It would be presuming to attempt to describe or predict the method that is likely to receive the widest approval.

Molded Plywood Housings

This same flexible molding technique, that has been outlined for hulls, is equally adaptable to superstructures, which can be thoroughly streamlined above, as the hull is streamlined below. Roof and sides can be made in one piece, using large molds. Openings can be cut for curved windows, and the lightness in weight, the absence of seams and joints and the bracing effect of the shell construction emphasize the advantages of plywood in this new and growing application.

It may be a bit daring to predict that eventually both the hull and the superstructure may be molded in one unit, with the total elimination of all seams and joints, and the strength/lightness characteristics of the plywood shell construction.

Plywood Pontoons

An interesting plywood development is the two-piece pontoon boat, suitable for temporary bridges and the like. An example is shown in Fig. VIII. 11, in which the shape permits nesting together

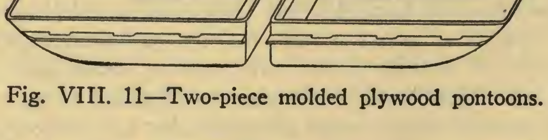


Fig. VIII. 11—Two-piece molded plywood pontoons.

in 8- to 10-inch steps, for convenient transportation. The plywood units are much lighter than those of solid wood or metal, reducing the man power required for handling in emergencies. Sizes and thicknesses are in the course of development, with indications that such pontoons can be designed to carry 10- to 15-ton vehicles with safety.

Adhesives for Boat Construction

Flat plywood, used in boat construction, should be made with hot-pressed, phenolic-resin adhesives that possess the highest durability known, even under most exacting service.

Molded plywood is preferably made with similar phenolic-resin adhesives, although excellent results have been obtained with urea resins. The ureas are somewhat below the durability standards of the phenolics, but when well protected with surface coatings will give excellent life. In most instances the deterioration of the wood, where exposed by improper finish, inefficient maintainence, or casualty, will take place before the resin adhesive, of either type, shows signs of weakening.

For the assembly operations in boat construction, where heat cure is not practicable, the so-called cold-setting ureas are suitable. Such joints are frequently reinforced by mechanical fastenings and should be well protected from exposure by adequate surface coatings.

BURIAL CASKETS

The manufacture of coffins and caskets is one of the oldest of the woodworking industries and is widely distributed geographically. Wood has been the predominant raw material used in casket manufacture through the ages, due to its wide distribution, its ease of working, and its many elements of attractive appearance.

The story of the decoration and embellishment of burial caskets would make an interesting tale of the human attitude toward the phenomenon of death. In recent years, finished hardwood coffins have grown in popularity, as contrasted with the conventional cloth-covered casket. This has led to the use of the more attractive cabinet woods, such as mahogany, walnut, oak, and the like. In this development, decorative veneers and plywood have found increasing utilization, under processes and techniques that closely resemble those used in furniture and its allied lines (page 255). There are a number of casket designs where the ends of the casket are semi-circular, and are made of an all-veneer construction, much like that shown in Fig. II. 10. These ends are pressed and glued in pairs of forms. Pressure in one direction is not adequate for a complete semi-circle, so that additional pressure or clamps are required at right angles to the direction of principal pressure.

Developments are under way to utilize molded plywood, for the convex, semi-cylindrical lids, as well as for the sides and ends. This would permit the use of the hot-pressed resin adhesives, with a definitely greater durability and moisture resistance for storage, than

is now possible with the conventional glues and solid wood constructions. This method would require a pair of metal dies for the lid, with removable and adjustable sections to adapt the pairs of dies to the different lengths and sizes required. The thickness of the lid could be reduced from the present ¾ inch to approximately ⅜ inch, without sacrifice of essential strength. The sides and ends, also, could be pressed out of thin plywood, and all molding effects provided in the original forming of the plywood, somewhat as shown in Fig. VIII. 12. In this illustration the plywood is shown in full

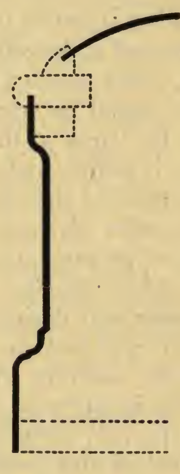


Fig. VIII. 12—Molded plywood side of casket, with attachment members shown dotted.

lines, with inside corner posts, top trim and bottom shown dotted. Such a use of plywood and veneer permits the use of various figured wood effects that cannot be secured in solid lumber. The sides and ends can be made in a pair of dies that are long enough to include the largest casket dimensions, or the dies can be made of sufficient size to include a side and end in each pressing, to be cut apart for assembly purposes.

While this process is not in extensive use (1941) it is under thorough consideration by several prominent coffin manufacturers. It is recognized as a distinct advance in the direction of more beautiful caskets, lighter in weight, more sturdy than those in use, and far more resistant to moisture exposure.

Another method of casket construction is that of applying veneers on a sheet metal base, along the line of the "Robertson Bonded Metal" process (page 95), where cloth is firmly attached to the metal

with a low-temperature solder, and veneers are bonded to the cloth-covered metal by a phenolic-resin adhesive. This permits the same shaping and forming in plymetal as is described above for plywood, and offers the combination of the durability of the metal and the appearance of beautiful veneers.

CONSTRUCTION AND BUILDING

Plywood vs. Lumber

Plywood has been correctly called sheeted lumber. Its strength is distributed in both directions, and it can be used with little regard to normal grain directions. It can often be used advantageously, where the higher cost of the plywood is largely offset by the lower cost of attachment and erection. Such uses are areas where many narrow boards would be required to equal the area of a single sheet of plywood. Little economy can be found in the use of narrow pieces of plywood, since solid lumber is stiffer, and there are practical difficulties in concealing the end wood of the inner plywood layers, which are of opposed grain to the outer plywood surfaces.

These structural grades of plywood are made mostly of Douglas fir on the Pacific Coast. Their standard sizes are listed on pages 87-9, and the standard grades and designations are given on pages 327-8. Diversified stocks are available in most retail lumber yards.

There is a tendency in the building trades to underestimate the amount of nailing required in plywood to develop the necessary structural stability. Since the only connection between the plywood surfaces and the framework of the structure is in the nails, they must be of such a size and frequency as to give adequate strength under adverse conditions. If and when the technique of using adhesives is developed for house construction, the connection between surfaces and framework will be much more dependable.

Another important factor in the design of houses to be erected from plywood sheets is the unit size of plywood sheets available. The usual structural size is 4 by 8 feet, which divides easily in either direction, into the usual 16-inch spacing of conventional studding. Larger sizes in plywood carry higher cost differentials and are seldom economical. Hence, the adoption of a 4-foot module or multiple, in the design of any plywood structure, will conform to standard economic sizes with a minimum of cutting and a maximum of utility.

Another factor to be considered in the use of plywood in construction is the practical elimination of cracks between the boards, thus making the structure far more wind-proof, and serving the purpose of insulation in either hot or cold weather.

The use of plywood for interior wall exposure eliminates the hazard of excessive moisture resulting from the use of wet plaster. The proper drying out of a plastered house is well known as a time-consuming process, which, if neglected, will cause serious damage to interior wood parts. This all-plywood construction, without plaster, is often called **Dri-bilt,** or **Dri-wall.**

Plywood Wall Sheathing *

Sheathing is the outer covering over the framework and exterior walls of the house, whereas wallboarding usually applies to the similar covering of the interior partitions. In these locations plywood can be used instead of lumber or plaster, with the various advantages mentioned above. With adequate nailing plywood contributes definitely to the strength and sturdiness of the house, far more than does the conventional boarding, even when laid diagonally. Builders are coming to use plywood more and more for interior wall covering, in lieu of lath and plaster.

The following nailing schedule (Table VIII. 1) is recommended, based on 16-inch spacing of studding, on 6-inch nail centers around all edges of the plywood, and on 12-inch nail centers on all intermediate studding.

Table VIII. 1
Nailing Schedule

Location and Type	*Thickness*	*Nail Size*	*Remarks*
Interior Walls			
Hardwood Plywood....................	1/4"	6d	Without glue
	1/4"	4d	With glue
Douglas Fir Wallboard.................	1/4"	4d	Common nails
	3/8"	6d	Common nails
	1/2"	8d	Common nails
Exterior Walls			
Douglas Fir Sheating (Inside)............	5/16"	6d	Coated nails
	1/2"	6d	Common nails
	5/8"	8d	Common nails
Douglas Fir Siding (Weather exposed)....	3/8"	6d	Common nails
	1/2"	8d	Common nails

Casing or finishing nails may be used on interior work, common nails on exterior construction.

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* Acknowledgment is made to the Douglas Fir Plywood Association of Tacoma, Washington, and to the United States Plywood Corporation of New York City for many of the structural data on plywood which follow.

Sub-flooring

Plywood gives a relatively level, smooth and jointless foundation on which to install a hardwood or linoleum floor. It also serves as insulation, as protection against drafts from below, and serves as a horizontal diaphragm to resist earthquakes and high winds.

Sub-flooring, laid on joists that are spaced on 16-inch centers, is adequate if 5/16 to ⅜ inch thick. This anticipates a ⅝- to 13/16-inch finish flooring nailed through to the joists. It is more general practice to use ½- to ⅝-inch plywood. The ½-inch is calculated to carry a uniformly distributed live load of 100 pounds per square foot, with a deflection of 1/360 of the span for joists placed on 16-inch centers. Tests made on ½-inch plywood and 13/16-inch finish flooring deflected only 1/10 inch under a concentrated load of 900 pounds, whereas a grand piano imposes a load of approximately 300 pounds per leg. Normal residential requirements are for approximately 50 pounds per square foot distributed floor loading. It is recommended that all nailing be on 6-inch centers on all plywood edges and 12-inch centers on all other bearings. Nail sizes are 6d for 5/16- to ½-inch plywood, and 8d for ⅝-inch thickness.

As a base for linoleum, or other resilient floor covering, it is customary to use ⅝-inch plywood, although ½-inch has been used successfully. The nailing schedule should be as above. Unsupported plywood joints, between the joists, should be reinforced with headers, to eliminate deflection at the edges. Since most resilient flooring manufacturers have developed standards for sub-floors, their recommendations should be consulted.

It is often economical to use plywood first for concrete form work for the foundations and later for the sub-floors. Some thought should be given to the size and thickness of plywood that will be suitable for this dual purpose.

Roof Sheathing

Plywood simplifies the roof construction, as it does the wall and sub-floor construction, and provides not only a smoother and more pleasing ceiling for the attic, but also is wind-tight and serves a useful insulation purpose. The bracing effect of plywood roof covering is far greater than that of narrow roof boarding.

The following schedule (Table VIII. 2) is recommended by the Douglas Fir Plywood Association for roofs, and for the thickness and spacing of plywood roof sheathing, with the face grain of the plywood lengthwise across the rafters.

Table VIII. 2
Plywood Roofs

Roof Load	*Max. Rafter Spacing*	*Thickness*
20 pounds sq. ft.	20 inches	5/16 inch
	24	⅜
	30	½
	36	⅝
30 pounds sq. ft.	17½ inches	5/16 inch
	21	⅜
	26	½
	33	⅝
40 pounds sq. ft.	16 inches	5/16 inch
	19	⅜
	24	½
	29½	⅝

The roof nailing should be the same as specified for sub-flooring.

Plywood for Concrete Forms

Plywood of special construction types is made for concrete form work, surface oiled at the mill and edge sealed. It is trade marked **"Plyform"** by the Douglas Fir Plywood Association. The usual thicknesses for flat form work are ½ and ¾ inch. Liners of ¼ inch are often used for curved surfaces, but require more than normal bracing.

Plywood for concrete form work can be used from six to twelve times, and often for longer periods if the nailing edges are trimmed off to the next smaller standard size.

Plywood is much preferred to solid lumber for form work, as it leaves smoother concrete surfaces, practically without fins, and requires a minimum of rubbing and finishing. The costs of erection are greatly reduced and the appearance distinctly improved.

The plywood thickness required depends on the stud or joist spacing, but a general standard is ⅝ inch, with framework spaced on 12-inch centers. This will normally deflect only 1/25 inch under a load of 500 pounds per square foot.

Nailing should be reduced to a minimum by the location of the frame pieces. Usually 5d common nails are adequate for ⅝-inch and under, while 6d are preferable for ¾-inch plywood.

Plywood can be **bent dry** to the curvature shown below, without rupture, as indicated. Complicated and reverse curves can be bent after **steaming** (only on phenolic resin-bonded plywood) and then properly braced in position.

Plywood Thickness	Minimum Radii	
	Lengthwise	Crosswise
1/8″	1′ - 3″	8″
1/4″	2′ - 0″	1′ - 3″
3/8″	4′ - 6″	3′ - 0″
1/2″	8′ - 0″	6′ - 0″
5/8″	10′ - 0″	8′ - 0″
3/4″	12′ - 0″	10′ - 0″

Hot-pressed, resin-bonded plywood can be steamed and curved to substantially smaller radii.

Plywood Flooring

One of the most serious shortcomings of the ordinary top (or finish flooring, as contrasted with the sub-floor) flooring of solid lumber is its marked tendency to shrink and swell widthwise, depending on the surrounding atmospheric conditions. Solid flooring will shrink when houses are heated, and show distinct open cracks between the individual boards, sometimes wider than the thickness of a 5-cent piece. Normally these cracks will close up when artificial

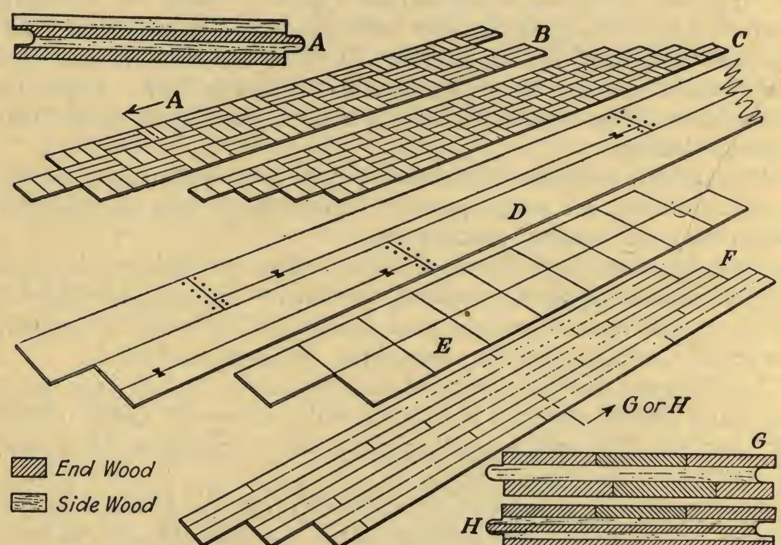


Fig. VIII. 13—Standard prefinished plywood flooring.

A—4-ply parquetry in cross-section, segment-sawn face on a 3-ply foundation. *B*—6-inch parquetry squares in standard 6-foot lengths. *C*—4-inch parquetry squares in standard 6-foot lengths. *D*—random plank with plugs and butterfly connectors. *E*—plank parquet, 9-inch squares. *F*—standard strip plank in 6-inch widths, 8 feet long. *G*—3-ply strip plank in cross-section, with resawn lumber back and crossings. *H*—5-ply strip plank in cross-section, with veneer foundation and segment-sawn face.

heat is not required. If the under side of the flooring is poorly protected and becomes exposed to moisture, the edges will cup upward, as often happens when a solid wood floor is laid on a concrete base It may be thought that thoroughly dry flooring (5% M.C.) will have little opportunity to swell, which is true, but often when such dry flooring is laid, it is sure to swell under the action of moisture in damp seasons, and is likely either to push out the side walls, or to draw the nails and produce disconcerting humps and ridges, sometimes several inches away from the sub-floor. Another difficulty with solid floors, of the tongue and groove type, is the splitting of the tongue during nailing, resulting in loose and squeaky floors. The problem of properly laying a solid wood floor, in a new building damp from plastering and a lack of heat, requires far more patience than most contractors and owners can manifest, and consequently flooring is often laid under adverse conditions that encourage the swelling and shrinkage suggested above.

Plywood flooring offers an adequate solution to these problems, although cost limitations have been somewhat of an obstacle to its wider adoption. Plywood permits the use of wider floor units, which reduces the cost of laying and decreases the number of joints; plywood flooring can be accurately and smoothly sanded in the factory before laying, permitting prefinishing, and avoiding the complications and expense of sanding after laying; plywood tongues are non-splitting; shrink and swell in plywood floors are practically negligible; the thickness of the top layer of veneer can be such as to permit all the refinishing that can be done on solid flooring without exposing the tongue and groove; parquet flooring, of a wide variety of patterns, can be made up into plywood strips, greatly decreasing the cost of laying; and there are many other minor advantages.

A number of these desirable qualities of plywood flooring can be noted in the illustrations and captions of Fig. VIII. 13.

Plywood Doors

Very few doors of solid lumber are now used in buildings designed for human occupancy. The inevitable shrink and swell, with the consequent warping and twisting (since doors are often exposed to quite different atmospheric conditions on their opposite sides) have resulted in the use of plywood which reduces these difficulties to an almost negligible quantity. The advent of the resin adhesives, superseding the far less water-resistant conventional adhesives, has overcome the chief remaining weakness of plywood door construction.

Doors for human use, in general, can be divided into two major classifications: the **panel door,** with thick stiles and rails and thin panels; and the **flush** or slab door of uniform thickness throughout. The latter can be divided into two sub-groups: those with continuous lumber centers of a lightweight wood, commonly called solid; and those with more or less hollow centers, to decrease the weight still further. All types of doors are preferably made of plywood for the reasons indicated above.

Panel doors were made long before plywood came into general use, with thin edge-glued lumber panels, which were often tapered to go into grooves, but frequently were considerably thicker in the center for strength and pleasing appearance. Doors in old houses, with solid lumber panels, almost always show the evidence of the shrinking and swelling of the panels which may be from ¼ to ½ inch in an ordinary width door, and often as much as 10%.

It is known that the first use of Douglas fir plywood panels was in door construction on the Pacific Coast as early as 1905, and it is believed that hardwood plywood panels were used in doors in the 1890's, perhaps even earlier. At first the stiles and rails of these doors were of solid lumber, but sometime around 1910-15, it was found that plywood, or more correctly laminated wood, carried the plywood advantages into the whole surface of the door. These stiles and rails of laminated construction usually had ⅛-inch veneer faces, to permit the normal machine operations that had been customary on solid pieces, and the edge strips of the core were generally of the same species as the face veneers. The detail of this construction is shown in Fig. VIII. 14. If such plywood panel doors were used for

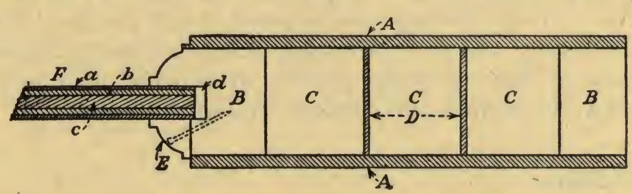


Fig. VIII. 14—Panel or stile and rail door of plywood.

A—face veneer on stile or rail, usually ⅛ inch. *B*—edge strips on stile or rail, to match face veneer *A*. *C*—core strips, usually of pine. *D*—reinforcing core strips of veneer, often omitted. *E*—molding to hold panel, frequently integral with strip *B*. *F*—plywood panel, 5-ply: (*a*) face veneer; (*b*) crossing; (*c*) veneer core; (*d*) clearance space.

other than interior openings, a water-resistant adhesive was necessary to protect against weather exposure. The recently developed resin adhesives have answered this requirement fully.

There is a wide variety of styles in panel doors, from one large vertical panel to a number of small horizontal panels, or a combina-

tion of both vertical and horizontal panels, as can be noted from trade catalogs and architectural treatises.

The flush door is undoubtedly derived from the earlier slab door, designed originally for strength and adequate protection in outer doors. Many of these earlier doors were almost massive in construction. Just when the flush plywood door came into use is unknown, but probably early in the twentieth century, as the plywood art developed. Until the advent of water-resistant glues, particularly the resin adhesives, it was used mostly for interior doors, such as schools, libraries, hospitals, offices and institutions, where sturdiness, sound insulation and the sanitary quality of having no ledges and cracks to afford lodgment for germs and dirt were important considerations.

A typical construction for such flush plywood doors is shown in Fig. VIII. 15, where lumber is used throughout for the core or

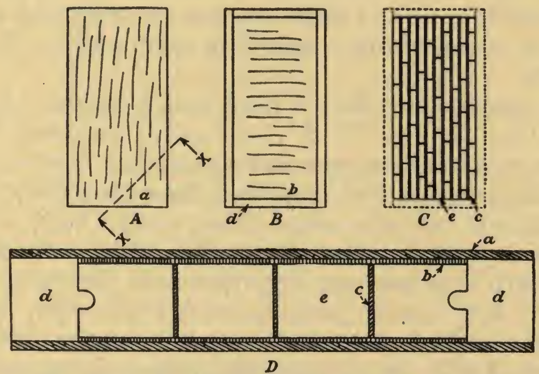


Fig. VIII. 15—Flush or slab door of plywood.

A—flat view of door, showing endwise grain of face veneer. *B*—same view before applying face veneer, showing crosswise grain of crossband veneer, as well as edge bands or rails. *C*—same view, below crossband, showing core construction before railing. *D*—enlarged cross-section on line *X-X* showing details of construction: (*a*) face veneer, usually 1/16 inch thick; (*b*) crossband veneer, usually 1/16 inch thick; (*c*) reinforcing core strips of veneer, also used as glue-spreading media, which are often omitted; (*d*) protective rails or bands to match face veneer; (*e*) core blocks approximately 1⅛ inch, usually of pine.

center layer. The illustration shows a concealed crossband construction, where the edges and ends of the crossband layer are concealed or covered by the rails or edge strips of lumber. This construction requires two plywood gluing operations, the first for the core and crossband, which is then trimmed and the rails attached; planing or double surfacing is necessary to bring to uniform thickness for the subsequent gluing, after which the face veneers can be applied as a second plywood step. Many flush doors are made in

one plywood operation, with ends and edges of crossbands exposed, but they are not regarded as of as good quality or durability as the concealed crossband type. The door cores are usually made of relatively small pine blocks which ordinarily are waste cuttings from large planing mills. This type of core is both economical and efficient, since the use of small blocks eliminates the twisting tendency that might come from the use of wider or longer pieces of core stock.

This type of flush plywood door can be made with inner or outer layers of sheet asbestos for fire-retardant construction, using hot-pressed resin adhesives. Resin adhesives behave differently under fire exposure than do the usual glues. The latter are weakened by heat, so that the layers of veneer peel up and aid combustion, while with resins, the adhesive grip is heat-resistant and holds firm until the wood is burnt away. A comparable analogy is the burning of several separated sheets of paper, as contrasted with attempting to burn a closed book. Flush doors can also be made with inner layers of metal, an example being a lead-lined door, used for X-ray rooms in hospitals.

Another type of flush door is made with a hollow center or core, as is illustrated in Fig. IV. 5. This results in a very lightweight door, often used in apartments. Its construction consists of a series of small compartments, like a type box, halved together, and notched into the stile and rail core strips. These interior compartments may measure from 2 to 3 inches in either direction, and are made of wood or fibreboard, some ⅜ inch thick by 1 inch wide. The edge strips of the stile core are provided with extra width to accommodate the door hardware.

A variant of this type of hollow flush door can be made with the usual stile and rail framework, without small compartments, but with large interior apertures where the panels are usually inserted. Such doors are likely to have concave surfaces over such large hollow spaces, and are often resonant. This can be rectified by filling the hollow spaces with blocks of fibreboard or cork, of a suitable density to keep the outer plywood flat.

Both types of hollow doors require a two-stage plywood operation, one to 2-ply or 3-ply the outer layers, and the other to attach these outside plywood sheets to the hollow center or core.

Interior Trim and Partitions

Plywood is extensively used for interior paneling and built-in cabinet work, chiefly for its artistic effect. Both flat and curved plywood, with plain and figured faces, are employed. Since such

plywood is practically all custom-made, the flitches of veneer are frequently selected to secure the same or similar figure combinations in panels and doors in a room or suite of rooms. In the plainer woods, stock panels can be used with satisfactory results.

Where room interiors are of plaster or masonry, it is possible to secure these effects by the application of Flexwood. This is a very thin veneer, reinforced with a cloth backing, and hung in the same manner as wallpaper. This may often conform with municipal ordinances in restricted areas, where fireproof construction is required.

Office partitions, both fixed and movable, are usually made of plywood for appearance, finish and lightweight.

Plymetal, a special type of plywood, with one or more outer or inner layers of sheet metal, is frequently used in metropolitan areas, where ordinary plywood would be barred by building restrictions. The use of inner metal layers provides a fire-resistant background on which can be displayed attractive wood and veneer effects, for thin partitions adjacent to masonry walls. Asbestos cores for the plywood, as explained under shipbuilding on pages 232 to 233, provide another basis for using plywood under similar conditions, where fire resistance is demanded.

Elevator cabs and enclosures are nearly always made of some type of plymetal, where wood beauty and metal non-inflammability are both essential. Much of this elevator enclosure work is a resin-bonded combination of "Robertson Bonded Metal," a cloth-covered metal described on page 95, combined with face veneers. This is such a thin plymetal, without cores and crossing, merely 2-ply, that it can be bent, curved and formed, much as is done with sheet metal.

Interior paneling in homes, within a modest price range, is often constructed of thin plywood, ¼ inch thick, in which case the studding must be carefully set to a true line, or properly furred out.

Some attention is being given to standardized plywood wall paneling that can be sold by the lineal foot of wall space, using panel sizes that meet the normal spacing of studding. Lumber trim members can be properly grooved and the cost of installation is thus greatly reduced. Such plywood paneling could be merchandized in packages, and thus brought within the reach of modest home owners.

Prefabricated Houses

The lure of prefabrication has intrigued many, and it has been hailed as the ideal solution to our many housing problems. As a matter of fact, prefabrication is very old and for many years has been practiced to a greater or less degree in almost every structure. It

consists in utilizing the shop or factory, with its trained mechanics and labor-saving machinery, to produce sub-assemblies for housing. Most of these can be done more advantageously under factory conditions than in the field, where a premium is placed on handwork and little machinery is available. Obvious examples are doors, windows, door and window frames and casings, built-in cabinets, predimensioned lumber, moldings and the like.

The recent emphasis on prefabrication is merely an attempt to make larger sub-assemblies in the factory, while simplifying and reducing the more costly field erection. Examples are sectional walls, roofs and floors, that can be completely assembled in relatively large units in the factory and erected by bolting together on the foundation. The lightness and strength of plywood lends itself to the construction of such units far better than ordinary solid lumber. Some have gone so far as to prefinish these units before erection. There appear to be two major problems in prefabrication, that of rigid standardization and that of relieving the opposition of the building trades, who think they see a menace to the continuation of the many divisions and groups of skilled artisans that have grown up in the construction industry.

In the matter of standardization, it is essential that a module, or least common denominator of size, be adopted that will accommodate the largest number of possible and desirable combinations. One school of thought advocates 4 by 8 feet, the size of a standard stock panel, which will accommodate a normal door or window, and which answers reasonably well for small houses. In fact, few authorities visualize the use of prefabrication for large houses, and the top limit is often set at about six rooms. While most advocates recommend vertical modules, there are those who believe a horizontal module better, and actually use the horizontal panels of plywood as part of the load-carrying structure. So far no widely accepted method or type of standardization has emerged from the many independent and unrelated types of prefabricated houses. There seems to be no recognized authority to establish, govern and regulate such standards, and their gradual development and elimination is costly and requires long experience.

Still another problem in standardization is the public recognition of the fact that standardization in homes is as desirable as in automobiles, sewing machines, refrigerators, and the like. Most home owners prefer to emphasize the individuality of their houses, and in this they are encouraged by the architectural profession. However, an excellent case can be established for standardization and its resultant economy.

Little genuine progress in the realization of basic economy can be made until the mass production of houses or house units can be developed on a progressive assembly line, as other standardized products are made. So far, no adequately equipped and financed concern has forged to the front in this prefabrication field.

There are several theories of prefabrication, that have made substantial progress, among them can be mentioned:

Complete factory sub-assembly, at central points, where reasonably large portable units can be conveyed short distances and erected with a minimum of field labor, which can be relatively unskilled, and available everywhere.

Factory standardization, with many producing factories favorably located near raw material supplies and plentiful labor, and standardized parts are shipped from many points to the erection site. These standardized parts are much smaller than the units mentioned above, and therefore can be transported more economically. While they are prefitted, yet their field erection is considerably more complicated than the large units, and requires experience and skill.

There are a number of intermediate theories that lean one way or another, and combine the above major theories in varying proportions.

There are a few outstanding advantages in prefabrication that lead many engineers and architects to feel that some type of prefabrication will eventually be developed that will afford distinct public benefits. Among them may be suggested:

1. Adhesives and glue give greater rigidity and durability than nails. These can be employed far better under factory conditions than in the field.

2. Stressed skin constructions, with plywood sheets firmly glued to frame members, afford the necessary strength and rigidity, with far less material than is used in the conventional building methods.

3. There is little valid defense for doing by hand in the field what can be done more quickly, more cheaply and better in the factory.

4. Standardization has always resulted in ultimate economy and public benefit, but its processes of growth are often slow.

5. The trend is distinctly away from large houses, and definitely toward smaller homes, where maintenance and operation impose fewer burdens on the wife, mother and housekeeper.

A detailed description of the various methods that are in use is far too complicated for presentation here. A successful type of prefabricated house is shown in Fig. VIII, 16. Both government and private publications are available for those who wish to study them.

Trade publications, in the spring of 1941, reported that some 45 companies were engaged in making prefabricated plywood houses, averaging approximately 5000 square feet of plywood per house. Two thirds of these companies were on the Pacific Coast, and it was further reported that around 2000 houses were being erected monthly.

Courtesy, Gunnison Housing Corp.

Fig. VIII. 16—Gunnison prefabricated house in Indianapolis.
Porch and quoin corners are added to relieve the monotony of standardized designs.

It is quite evident that modern plywood will play an important part in the prefabricated house of the future, when it finally wins its place in American life.

CONTAINERS AND SHOOKS

The container industry, in a broad sense, includes a wide variety of packages for shipping, storage and dispensing. Some of these types have long been made of plywood, such as the plywood shook. In other instances, the recognition of plywood advantages is just beginning, and its adaptations to package uses are in the stage of development. The availability of resin adhesives, with their mold resistance and waterproofness, is rapidly expanding the use of plywood products into the barrel and keg field. The advantageous strength/weight ratios of plywood are of especial value in the shipping container field.

Plywood Shooks

The plywood shook industry is known to have been active in Maine in the early 1900's, at which time silicate of soda (liquid

glass) was one of the principal adhesives, partly because of its moderate cost compared with the animal glues then available, and partly for its water resistance. It was found, however, to be quite lacking in durability, which may not always be a fault in shipping containers. At the present time both vegetable (cassava) and soya bean meal glues are extensively used in making plywood shooks. The latter can be applied successfully and economically to relatively wet veneers, up to 25%, which reduces the cost of veneer drying and permits handling with far less breakage than normally dry veneer. The hot-pressed resin adhesives seem particularly adapted to shook manufacture, due to the elimination of time required in clamps and the reduction of floor space for bale storage, but no substantial progress has been made in this direction as yet.

A plywood shook is essentially a sheet of thin plywood, 3-ply, reinforced at its ends and edges with wood cleats, clinch-nailed into the plywood. Intermediate cleats are sometimes used as stiffeners. Strength and closure are the principal requirements, with little emphasis on appearance except in certain cases. The thickness varies from 3/20 to 3/28 inch, with considerable favor for 3/24 inch, depending on strength and cost factors. The three plies are of the same thickness, so that the entire product of the log (in rotary cutting) can be used, the better selection for faces, the next for backs, and the remainder for centers or cores which only have to hold together until plied up. The veneers are not trimmed or taped, but laid edge to edge after the glue is spread. The cleats are usually saw mill edgings, gang nailed with automatic machines. See Figs. VIII. 17 and VIII. 18. The cleats are of such a size and so arranged as to permit assembly into packing cases, with nails at the corners. Wire binding processes are also used for plywood shook assembly.

Some developments are in progress toward bending, under heat, the ends and edges of plywood shooks, to serve as stiffening and provide corner nailing, thus eliminating the weight of the cleats. Still other studies are in progress to corrugate the plywood in the bonding operation for additional stiffness. Neither of these methods has reached the stage of production as yet.

The advantages of plywood in shook manufacture are its lightness compared to its weight, its non-splitting qualities and tightness compared to solid lumber.

The development of corrugated paper cartons has substantially reduced the use of plywood in the small package field. Plywood shooks can be re-used several times.

Courtesy, Atlas Plywood Corp.

Fig. VIII. 17—Plywood shipping case for textiles.
Note solid lumber cleats for bracing and corner nailing.

Courtesy, Atlas Plywood Corp.

Fig. VIII. 18—Plywood crate for heavy packages.
The plywood serves principally as a closure.

Plywood Drums

Many chemicals and other products, in dry form, require non-metallic shipping containers. The cylindrical drum is preferred to the rectangular box for several reasons, not the least of which is the absence of joints and corners. Plywood permits a lightweight and low cost, with adequate moisture resistance.

Plywood drums are usually made of flat sheets of plywood, curved in some type of roller machine, and joined together with some design

of metal fastener that penetrates the inside of the drum. One of the practical difficulties in the use of these drums is the necessity of installing bending and assembly equipment at the point of use, since transportation costs require shipping the drum parts flat. The heads or ends may be solid wood, with tapered edges, nailed in place. Wire bound and steel strapping reinforcement are sometimes used of such plywood drums.

Plywood drums can be made of many species of wood, but the cheaper varieties, such as pine, Douglas fir, gum and poplar, are more commonly used.

A process has been developed in Europe, but so far not introduced here, of making the drum sides of two sheets of resin-bonded plywood, with joints on the opposite sides of the cylinder, the two sheets being bonded together in a second operation, either with an expanding mandrel, or external pressure exerted circumferentially. In this type of drum the ends are "dished" and attached in place as shown in Fig. VIII. 19.

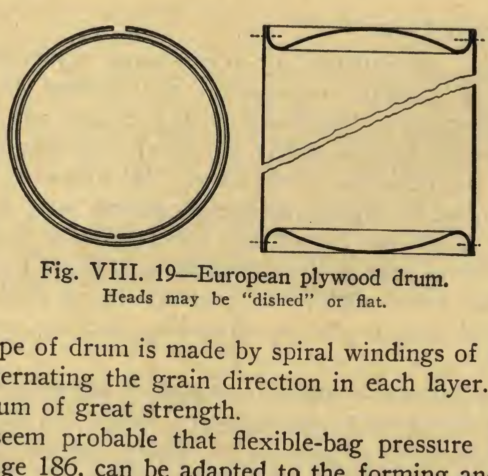


Fig. VIII. 19—European plywood drum.
Heads may be "dished" or flat.

Another type of drum is made by spiral windings of narrow strips of veneer, alternating the grain direction in each layer. This makes a jointless drum of great strength.

It would seem probable that flexible-bag pressure methods, described on page 186, can be adapted to the forming and bonding of drums, although no developments along that line have been reported.

Tobacco Hogsheads

This is a type of segmental cylindrical drum, some 50 inches high by 36 to 48 inches in diameter, made of flat staves about 4 to 5 inches wide. Each stave is stapled to three or four wire hoops, so that the entire side (circumference) can be flattened out for reshipment. They are used for the storage and transportation of dry tobacco leaves, and are steamed, with their contents, for some hours

at 160° to 170°F. The spaces between the staves permit thorough penetration of the tobacco leaves during this process. In the normal solid wood hogshead the ends are cleated together from narrow strips. These hogsheads are used for several years, and are subjected to these alternate wet and dry exposures.

Plywood is extensively used in these hogsheads, as it excels solid wood in non-splitting qualities and in lightweight. Douglas fir has been found satisfactory and within a possible cost range. The southern gumwoods can also be used for these hogshead staves and heads, and several of the other low-cost species will serve as well. The staves are usually about ⅜ inch thick, used without sanding, with cross-laid veneer cores.

Hot-pressed, phenolic-resin adhesives are required to withstand these repeated steaming treatments, although some success has been reported with staves made with soya-bean meal glue. Continuous plywood ends serve satisfactorily, as the slots between the staves are adequate for the steaming process.

Plywood Export Cases

Export cases, particularly for ocean-borne commerce, must be tighter than for domestic transportation. Plywood has little competition with corrugated fibreboard in such export uses. Solid wood can be used, but is heavier and is subject to shrinking and swelling, which impair the tightness of the case. The adhesives for plywood export cases must be highly moisture resistant, and, in the case of food products, must not impart any taste or flavor to the contents. The resin adhesives answer these requirements better than any of the other glues that are available. In general, export cases must be of thicker plywood than boxes for local uses, and are seldom subject to re-use.

In the Orient, tea is customarily shipped in plywood chests. Until shipping restrictions were placed on the Baltic Sea ports, much of this tea-chest plywood originated in Russia and the Scandanavian countries. During 1939 and 1940 many millions of square feet of plywood have been shipped from the United States to the Orient for making tea chests.

Export cases for heavy machinery and automobiles employ large quantities of plywood, which in general is of a higher grade than ordinary box shooks, both as to strength and adhesive durability.

Military Lockers and Tool Chests

The growth of the military organization of the United States, in the present defense program, has required many thousands of lock-

ers for the personal possessions of the soldiers and for portable tool chests for the many types of tradesmen required in maintaining an army, navy and air force on a war basis. In general, these are made of plywood that will withstand from 24 to 48 hours' soaking in cold water without delamination. Some grades of casein will pass these tests, but the resin adhesives are preferable. Species of wood are usually gum, poplar or cottonwood. Thicknesses are commonly 3/8 inch, 3-ply. Sound sanded surfaces are required, suitable for painting.

FURNITURE AND ALLIED INDUSTRIES

There is a wide variety of wood products made for use in homes, schools, churches, lodges, ships, offices, factories and the like, that can be manufactured more or less interchangeably in a well-equipped woodworking factory, although the size, grade and type of product will influence the assortment of machinery and amount of floor space required.

In general, these products are fabricated from wood as the principal raw material, with generous use of plywood. Most of the products in this group are completely finished in the factory and ready to use when shipped. There are a few exceptions, such as built-in cabinets, parts of bank and store fixtures, portions of school, church and office equipment, which are customarily finished after installation.

Space will permit only a brief outline of the various plywood uses that occur in these many branches of woodworking, classifying each product, in general, with its major field of utility.

Furniture

There are many branches in the furniture industry and some factories specialize in bedroom, dining room, living room or hospital furniture, while others devote themselves exclusively to chairs, tables, desks, or cedar chests. There are also factories that combine these products in various ways, to serve certain commercial fields. Hence the least confusing classification will be by type of products.

Case goods is a comprehensive term which includes bureaus, chifforobes, vanities, buffets (sideboards), chests of drawers, highboys, lowboys, and in general refers to enclosed cabinets with drawers, cupboards, alcoves, shelves, and other interior divisions. The plywood parts are usually **tops**, preferably of 13/16-inch, 5-ply, lumber-core plywood; **ends**, either of the same type of plywood, or of thin plywood grooved into posts or frame members; **doors,**

curved or straight of thick plywood, or thin plywood **framed**; **drawer fronts**, curved or straight, but almost always of ⅝-inch plywood or thicker; **drawer bottoms**, of thin plywood, fitted into grooves in the drawer sides; **mirror backs**, largely for protection; **dust bottoms** and **case backs** for closure and protection in concealed locations; and other miscellaneous uses.

Veneers are carefully selected for surfaces and locations that are seen as the item is in customary use, while the plywood in concealed locations may be of lower grade, designed for strength rather than appearance.

The flat plywood and its construction has been described adequately elsewhere. The selection of face veneers offers a plentiful range of choice, limited only by cost, skill, style, and the ability and experience of the designer. In better grades of furniture, competent manufacturers use only one-piece crossings under face veneers, to avoid the hazard of showing a slight line through the finish at the crossbanding joint, or possibly an impression of the tape used to join together piece crossings. Crossings of uniform thickness, when joined on a tapeless splicer, may be considered one-piece. Lumber cores in the higher grades of furniture are usually railed, or banded, as described on page 142, so that the exposure of end wood can be eliminated, and the use of molded edges made possible. Rails should be of the same material as the face veneer, or of a species that will take a similar finish.

There are a number of ways of making curved plywood which can be divided roughly into **thick curves** (½ inch and up) and **thin curves** (⅜ inch and less), although some methods apply to all thicknesses.

One of the oldest methods on thick plywood, still well regarded by competent manufacturers, is the sawn block core, which is illustrated in Fig. VI. 35. Face veneers and crossings with adhesives are inserted in the place of the saw kerf, and the entire block is clamped together while the glue sets. This method requires no forms or dies, and is therefore suitable for short runs or custom orders. It is not suitable for sharp curvatures, or unsymmetrical shapes, where the layers are likely to slip out of place under pressure.

Another method is an all-veneer construction, as shown in Fig. II. 10, where the layers of veneer can be bent easily during the gluing operation. This process requires pairs of curved forms, of the type illustrated in Fig. VIII. 20, and hence is only adaptable for fairly long runs. In this method it is customary to use thin crossbands for easy bending across the curve, with all layers between the crossings laid with their grain parallel to the axis of curvature.

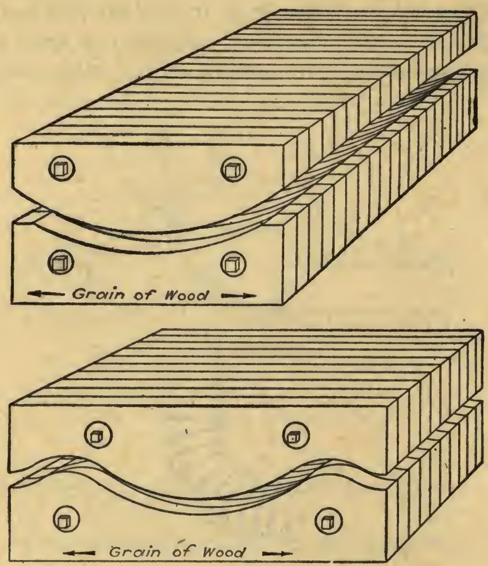


Fig. VIII. 20—Male and female forms.
Curves band sawn and finished on a shaper. Laminations bolted together after shaping.

A later method has been made available by the water-resistant adhesives which permit moistening or steaming for easier bending. In this process the back side of the curve is recessed by one of several ways, of which two are shown in Fig VIII. 21. The larger recess is more likely to produce the smoother curve, while the saw slot process must be very carefully done, to avoid the appearance of face veneer ridges between the saw slots. In both cases the recess is cut part way through the face crossbanding.

Thin plywood curves can be made in all-veneer constructions as shown in Fig. II. 10, and described above, but it is necessary to make the grain "with" rather than "against" the axis of curvature. They can also be made by the above recess process, although a small piece of veneer is often glued to the convex side, instead of the corner block attached by screws. This is shown at the bottom in Fig. VIII. 21, and the bending is done around a heated cylinder to set the resin adhesive before the release of pressure.

A third process for curving thin plywood is the Elliott Bending Machine, shown in Fig. VIII. 22, in which the plywood is passed through three heated rollers, and rocked back and forth, somewhat as steel sheets are rolled for cylindrical boiler shells.

In the finishing of furniture, it is important that both sides of the plywood be sealed with protective coatings, so that the absorption of moisture is prevented. An unfinished, or raw, side that becomes

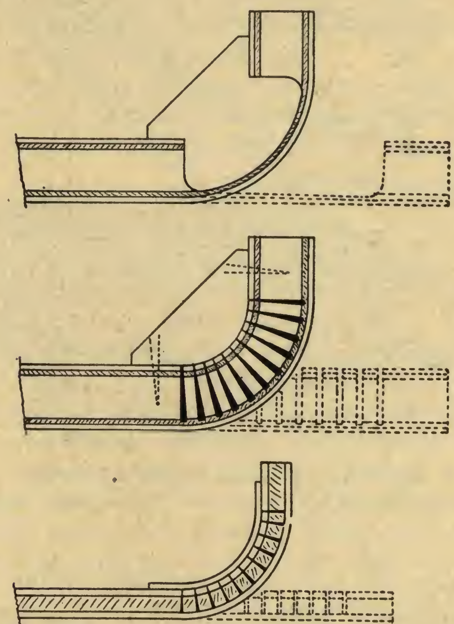


Fig. VIII. 21—Bending plywood with recessed backs.
Top—circular recess. *Center*—saw slots. *Bottom*—saw slots on thin plywood.

moist from the surrounding atmosphere will inevitably lead to internal stresses and warping tendencies.

Chairs offer little opportunity for the use of plywood. Perforated chair seats (see Fig. I. 8) were an early utilization of plywood, but are not much in vogue at the present time. Upholstered chair seats, including slip seats, are usually built up on a plywood base, which however is wholly concealed.

Decorative chair backs, required in some furniture styles, may be made with scroll sawed plywood, as in the shape of a lyre for piano use, or may be carved. In the latter case, plywood is made with thick faces and thin centers, to permit carving wholly within the outer layer of veneer. Juvenile furniture sometimes utilizes plywood for trays, seats, sides and backs.

A new type of chair has been recently developed, of all-plywood construction, band sawed and curved to the somewhat unusual shapes

shown in Fig. VIII. 23. This type of construction is believed to have originated in the Scandanavian countries, but has not as yet found wide acceptance in the United States. Other items of furniture have also been developed along this same line of design.

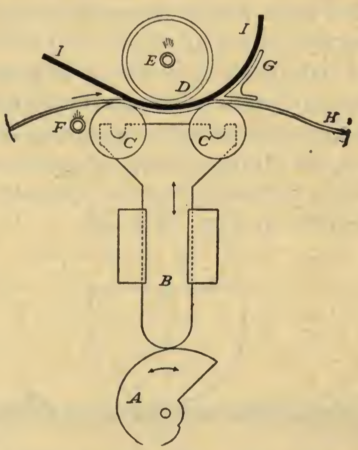


Fig. VIII. 22—Elliott dry-bending machine.
A—pressure adjusting cam. *B*—adjusting bar. *C-C*—lower roller supports. *D*—upper heated roller. *E*—perforated gas pipe. *F*—perforated gas pipe. *G*—guide. *H*—flexible metal band. *I*—plywood under bending.

Beds often have head and foot boards made of plywood with decorative veneer faces, either lumber-core construction for the better grades, or framed thin plywood where cost is an important fac-

Fig. VIII. 23—All-plywood chair.
All-veneer construction, made and curved according to Swedish designs.

tor. Curved plywood is often adapted to certain designs. Bed rails, which are usually concealed, may be made of plywood for strength and non-splitting qualities.

Cribs often have thin and framed plywood sides, of light-colored face veneer for enameling in white and near-white colors.

Whether a baby cab should be classed as a chair, a bed or a vehicle is a moot question, but in any eventuality straight and curved plywood find large use in its construction.

Tables customarily have a plywood top and utilize plywood in drawer fronts and bottoms, as in the case goods described above. The tops and leaves of dining tables are preferably of plywood. The approved core construction for circular dining-table tops is indicated in Fig. IV. 2. Curved plywood rims, or rails, to brace the legs and support the top, were formerly bent, as laminated wood, in the steel bending machine shown in Fig. VIII. 24.

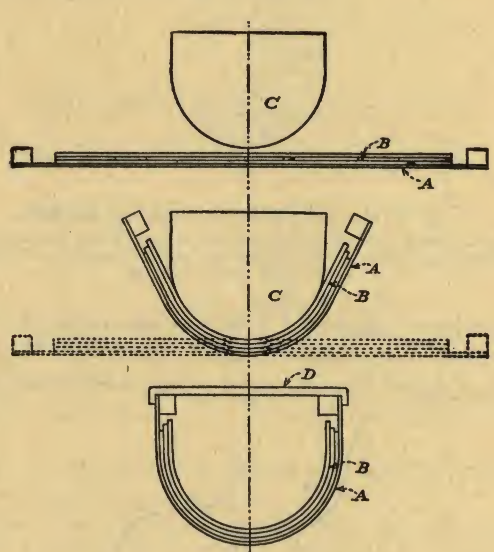


Fig. VIII. 24—Bending with flexible metal bands.

Upper—view shows plywood ready to be bent. *Center*—plywood partly bent. *Lower*—plywood completely bent, removed from the machine, and bands clamped as a drying rack. *A*—metal band. *B*—plywood to be bent. *C*—forming die. *D*—clamp to hold plywood U in shape until dry.

Desks, or writing beds as they are frequently called, almost invariably have plywood tops. They are often covered with linoleum or leather to prevent marring. The edges of such desk tops, which are often 1¼ to 1½ inches thick, are usually veneered to improve their appearance and conceal the plywood ends and edges to which some people object. Another type of desk-top construction is made with railed or banded cores and concealed crossbandings,

as shown in Fig. IV. 3. The rails or bands match the top veneer.

In the case of typewriter desks, with cutout tops for typewriter housings, internal rails are inserted in the lumber cores, as shown in Fig. VI. 6. The under portions of desks are similar in construction to that described under case goods above.

Bookcases resemble case goods in their construction, but with one new use, that of thin (1/16-inch thick) plywood, scroll sawed to design, and inserted in front of the glass of the door for decorative effect. Since shelves require stiffness, they are seldom made of plywood, since solid lumber is more rigid.

Cedar chests present a rather different method of plywood construction, i.e., that of the cedar interior. The top of the chest is of standard 5-ply construction, with sawn cedar veneer on its under side. The bottom, also, is of normal plywood with cedar top surface. However, the ends and sides are an unusual 2-ply construction, decorative veneer on the exterior, and cedar lumber of normal lumber-core construction on the interior. It is not a balanced construction, but with care and prompt assembly after bonding, little trouble is encountered with warping. The corners are of lock-joint construction and well braced at the open top. Another exception from normal furniture procedure can be noted in cedar-chest construction, that of leaving the interior unfinished to perpetuate the cedar aroma. It is important to exercise special care in cedar-chest construction to overcome these rather unusual features.

Occasional pieces include a number of incidental furniture items that do not clearly fall within the above classifications, but which use a substantial amount of plywood in their construction. Their problems of plywood utilization are much the same as those described above.

Pianos and Musical Instruments

Pianos have many cabinet-work problems in common with the furniture industry, but several highly specialized differences, aside from tone production.

In a grand piano, the rims are of curved construction (see Fig. I. 6), usually an assembly of ⅛-inch veneers, arranged in 8 to 12 plies of laminated construction with parallel wood grain. These rims are bonded with glue or adhesive on skeleton forms, using flexible metallic bands (inside and outside the rim on the form) to distribute the pressure and reduce the hazard of outside veneer rupture. The outer rim has a decorative veneer face, while the inner rim, half as high as the outer, requires strength rather than appear-

ance. This inner rim constitutes a ledge on which the working parts of the piano rest. One serious problem in the making of piano rims is the evaporation of the surplus moisture introduced into the veneers as a glue solvent, without destroying the shape of the rim. This requires many days of storage in an air-conditioned room, as the process must not be hurried at the expense of serious distortion in shape.

Grand piano tops are of plywood, preferably of quarter-sawn core stock lumber, to reduce warping tendencies. Poplar is the favored wood, with chestnut next. In order to keep warping at an absolute minimum, some piano makers ply up their grand tops in two operations, first the core and crossbands, which are carefully normalized, and then the face veneers.

The wrest plank, or pin block, in all types of pianos, is the earliest known industrial use of cross-laid plywood, dating back some hundred years to about 1830. The advantage of plywood here is its power to grip the shank of the tuning pins firmly, while allowing them to be tightened and loosened in tuning. Hard, or rock, maple is the best wood for this purpose, and the thickness of the individual layers and the total thickness vary with different piano manufacturers. While rotary-cut veneer is used, sawn veneer is preferred, because of the tightness of its grain.

In upright pianos, the case can be made much as described for case goods in furniture, but with greater care to avoid warping, which might disturb tonal adjustments. The wrest plank of plywood is similar to that of the grand piano. These facts are equally true for the larger upright pianos that were standard some years ago, as for the smaller types that are currently in high favor.

The player piano, with its perforated music rolls, has nearly become extinct, but during its heyday it used large quantities of plywood for its player actions and bellows.

The piano, as a musical instrument, reached its maximum of unit production about 1923, when the player piano was at its peak of popularity. The phonograph and the radio proved to be severe competition, and piano production declined steadily until about 1933, when its curve of production started to rise steadily.

Organs employ plywood in many ways for bellows, console cabinets and many internal parts. In the days of the old-fashioned cabinet organ that graced most homes of moderate means, plywood would have been a great boon to the manufacturers.

The makers of the modern electric organ find that only plywood will meet the extreme accuracy requirement of many of their parts. A plywood sheet, some 8 to 12 square feet in area, must not depart

from a true plane by so much a 1/16 of an inch, so precise are the standards in this intricate mechanism.

Drums are usually made with wooden cylinders or barrels, and plywood has been found superior to veneer. One of the newer techniques is to curve flat plywood on the type of bending machine shown in Fig. VIII. 22, scarf the ends together, and produce a firmer cylinder than was possible when the plywood was bonded in curved forms.

Phonograph cabinets, before the advent of the combination radio-phonograph, were a substantial outlet for plywood, both for interior and exterior parts. Even the horns were made of plywood.

The radio displaced the phonograph rather gradually, and at first most radios were housed in the larger console models. As the demand for cheaper radios grew, the cabinets became smaller and smaller, until now the making of small radio cabinets has become a highly specialized business of large volume. Except for the miniature plastic units, plywood is the standard material for all of these **radio cabinets.** The wood is inert electrically, the plywood cabinet is light in weight, sturdy in construction, attractive in appearance, and the technique of curved and bent plywood has advanced to such an extent that these small cabinets can be made with a minimum of costly cabinet labor. Radio cabinet designers seem to revel in curves, simple, compound and reverse, and to encourage the production of remarkably efficient plywood cabinet units in large quantities at moderate costs. In fact, the small radio cabinet has demonstrated the wide adaptability of plywood in mass production. In many of these designs the face veneer combinations of contrasting woods, inlays and marquetries, have gone so far that it is desirable to 2-ply these faces to reinforce their fragility before bending. This preliminary 2-plying also permits sanding off the veneer tape in the flat, before curving, thus greatly reducing the excessive sanding costs that would follow any attempt to sand the final cabinet shape. Many of these cabinets are finished by dipping, thus insuring a proper protective coating on the inside of the cabinet.

Church and School Furniture

This equipment has much in common with the types of construction outlined above, but also reveals a few special problems, such as curved pews, individual plywood seating and sound-retardent partitions and doors. In the matter of curved pews, plywood is again an advantageous material, since the thin veneer layers readily respond to the proper curvature during the plywood bonding process. The individual plywood seating, used largely for lecture rooms and audi-

torium, usually has a curved plywood back, mounted in a metal frame, and a reverse curved plywood seat that lifts up for entry. These backs are customarily made in sets of metal dies, as shown in Fig. VIII. 25, where about four curved plywood backs can be made in each opening. The variation in the concentricity of the curvature can be compensated by varying the thickness of the dies, from the center to the edge.

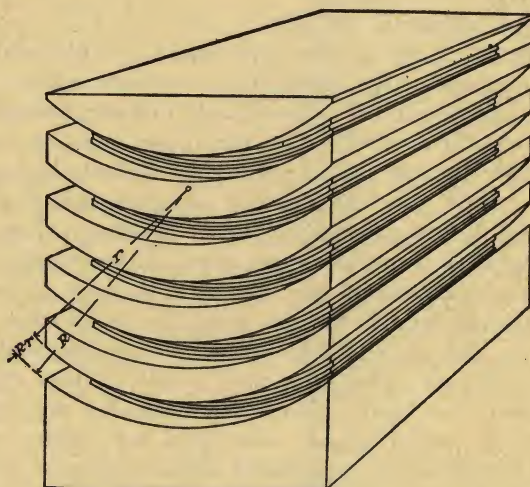


Fig. VIII. 25—Multiple male and female forms.

Producing approximately similar shapes. Preferably made of metal. R, outside radius of largest unit; r, inside of smallest unit; $r + R/2$ average radius; $R - r$, distance between cauls.

Sound-retardant partitions can be made best by combining plywood and fibreboards, as suggested in Fig. IV. 8. These may have veneer or plywood on one or both sides, or may be of hollow construction. In the latter case, the outer surfaces are of plywood, while the inner surfaces, next to the hollow space, are of fibreboard. This hollow construction is more efficient acoustically, where conditions permit its use.

Interior paneling and flush doors, appropriate for these institutional uses, are described on pages 243-7.

The above suggestions apply to theatre and movie houses, and also to the equipment of lodge rooms.

Hospital Equipment

While, in general, most of these requirements have been covered, there are a few special phases of the problems. Plywood is prefer-

able to metal, where it can be used, for its lightness in weight and its warmth to the touch. With the recently developed resin adhesives, baked enamel finishes can be applied to plywood, and thorough washing and cleansing can be practiced without fear of damage to the plywood.

The use of lead-lined doors has been suggested elsewhere, and offers adequate protection to X-ray laboratory rooms.

Telephone Equipment

Plywood is an appropriate material for the construction of switchboard cabinets and follows the processes of the manufacture of case goods in furniture. A plywood switchboard cabinet has excellent insulating value from the electrical standpoint.

The manufacturers of telephone booths also find distinct advantages in the use of plywood-fibreboard combinations, for pleasing exterior appearance and efficient sound insulation inside.

Store and Bank Fixtures

This industry can be considered as embracing equipment that is essentially of an interior trim classification, but requires high-class furniture material and workmanship. Plywood affords large areas of material of high quality that can be installed at moderate cost.

Counter fronts are a type of stock plywood carried in many plywood warehouses. The usual dimensions are from 36- to 42-inch lengths (vertically) by up to 12-foot widths (horizontally).

Modern fixtures include a large number of cabinets and storage cases, where the plywood advantages of lightweight and sturdiness are important.

Kitchen Cabinets and Cupboards

These are the product of still another industry, in which plywood is an important raw material. Many kitchen cabinets and cupboards are highly standardized and mass-production methods are employed to a great extent.

LAND TRANSPORTATION

Automotive

Trucks

Plywood has long been used in truck bodies, particularly for delivery cars. As in the case of airplane construction, the favorable strength/weight factors make plywood an excellent material for the large areas of truck sides and bodies. In the case of transport vans,

metal-clad plywood finds wide use, since the protective surface of the metal, outside and inside, combined with the stiffness of the plywood, results in an ideal side.

In most instances, ¼-inch plywood, faced on both sides with approximately 30-gauge galvanized sheets, is found to meet the requirements of truck body design. The plywood, if large sizes are required, can be scarf-jointed from smaller sheets, before the metal is applied. The metal covering sheets are usually attached to the plywood in a second bonding operation. Special adhesive mixtures are usually employed in metal to plywood bonding, consisting chiefly of casein and latex. Rubber compounds have an affinity for metals and blend well within casein. Some manufacturers interpose a layer of cloth fabric, between the metal and veneer, to reduce the rigidity of the bond between materials that behave so oppositely under the influence of heat. Hot pressing is not much used in wood to metal bonds, since the high temperatures of resin polymerization cause expansion in the metal which may cause unfavorable cooling stresses on wood-metal joint. The making of plywood-metal combinations is more fully described on page 95.

The cabs of trucks can be advantageously made of plywood, although its use here is less frequent than in the truck bodies proper.

Station Wagons

This type of automotive vehicle seems to be rapidly growing in favor, as well as in social standing, and has become almost indispensable for families who appreciate the convenience of a semi-truck for carting around a wide range of family and household equipment. Plywood has proved so entirely satisfactory for these vehicles that very few are ever made of any other material.

The plywood used in station-wagon construction is usually birch, at least for the face and back layers. Often poplar and gum are used for the inner layers. The adhesive is necessarily a hot-pressed phenolic resin, due to the extreme weather exposure to which station wagons are subjected. Panels set in the framework are preferably 5/16 inch thick, 5-ply, while less rigidly supported pieces may require thicknesses up to ⅝ inch.

An important feature in station-wagon construction is to protect thoroughly the plywood edges in the framework by some suitable moisture-resistant coating, usually applied during the course of the assembly.

Cheaper and thicker types of plywood may be used for station wagon floors.

Passenger Autos

The use of plywood in passenger autos has varied widely from time to time, and it has been used extensively for cowl boards, instruments dashes and running boards. As a floor material it has found consistent and continued use, because of ease of working, ability to be pressed to shape, strength and screw-holding power. Luggage racks and spare-tire supports, in current designs, require large amounts of low-cost plywood. Plywood is particularly favored for seat and cushion parts, since it lends itself to the attachment of upholstery by nails and tacks better than any other material.

Most of the plywood used for these purposes, in the more popular-priced cars, is of Douglas fir or gum, and is used more for strength than for appearances. The adhesive was formerly mostly casein, but in the last few years hot-pressed urea resins have largely displaced casein, because of moderate cost and excellent moisture-resistant qualities.

There have been considerable research and development toward the use of veneer-faced insulating materials for car interiors. The veneer is used for its decorative value, while the insulating backing has been made of plywood, fibreboards, and even sheets of flexible hair felt. With the development of air-conditioned cars, this use of veneer and plywood is likely to increase substantially in volume.

It is an interesting compliment to the decorative value of veneer that many of the interior decorative moldings and fittings are now made to imitate the appearance of wood grain.

There has been much talk of molded plywood for car bodies, fenders, and the like, and there are excellent inherent advantages in such a construction, but at the present time there seems little likelihood that this will occur. However, with the impending shortage of metals, it is a fertile field for investigation, and surprises may be in store for the car models of the middle and late 1940's.

Bus Interiors

Plywood, one of the recognized standard materials for bus interiors, has found wide use. It affords a strong and decorative material for the sides and ceilings, a sheeted material that can be curved to such an extent as is required where sides and ceilings meet, a durable material for floors and steps, and a sturdy material for baggage compartments. Overhead, hand-baggage racks have been made successfully of dense fibreboards for strength and face veneer for appearance, bonded together into efficient shapes for easy attachment and rigidity.

The base of the upholstered seat is usually of gum or fir plywood, because of its advantageous nailing qualities.

Metal-clad plywood has found wide use for bus exteriors, but is usually metal covered on one side only.

Trailers

Whether or not these nomads of the road are to become an important factor in American life is not yet clear. It is evident that, under certain conditions such as the rapid concentration of population for defense purposes, they may perform a temporary service better than any other available means. It is worth noting that none of the larger automobile companies have seen fit to adopt them.

Plywood is the principal material used in the construction of these trailers, which in the main are practically custom-made, rather than being made on a progressive assembly plan in a well-equipped factory. The adaptability of plywood for curving, for thin double walls and for exterior weather-proofness, as well as for interior serviceability and beauty, makes it the logical basic material.

One or two pioneers have been working on the problem of a fully streamlined trailer, made from molded plywood, bonded by flexible-bag methods, but so far without much encouragement from the purchasing public.

Railroad

Freight Cars

Large sheets of plywood are ideal for the linings of walls, ceilings and ends in freight cars, especially when contrasted with the many pieces of lumber otherwise required, with the excessive nailing required, and with the hazard of open cracks and leaks. Until the advent of resin-bonded fir plywood, railway authorities were reluctant to use the available plywood with its limited water-resistant adhesives. With the availability of the exterior grade of fir plywood, which is practically waterproof under the most severe conditions, plywood is rapidly forging ahead in freight cars, not only for interiors, but for the outsides as well. In fact, this grade of plywood has been found satisfactory for all parts of the standard box car above the sill plates, except the ends, which are usually of corrugated steel.

In a recent lot of refrigerator cars, the substitution of fir plywood for matched lumber, reduced the light (empty) weight of the car over 3000 pounds. There were only 20% as many joints and pieces, and the savings in shop labor were enough to cover the increased cost of the plywood beyond that of the usual matched lumber.

Details of this plywood construction are as follows:

Outside sheathing (siding) ..	1/2″ 5-ply fir, sanded
Sub-roof	5/16″ 3-ply fir
Main roof	5/8″ 5-ply fir
Sub-floor	5/16″ 3-ply fir
Main floor	7/8″ 7-ply fir
Side lining	11/16″ 5-ply fir
End lining	7/16″ 5-ply fir
Ceiling	7/16″ 5-ply fir
Bulkhead lining	7/16″ 5-ply + 1/2″ 5-ply fir
Doors	1/2″ 5-ply + 11/16″ 5-ply fir

Where plywood joints occurred without backing, metal splines were used. All plywood was attached by drive screws, except ceiling and sub-roof, where nails were used.

This construction, outlined in some detail, is typical of the exacting requirements of refrigerator-car construction. The ordinary box car will demand the same strength factors, but the interior atmospheric conditions will be much less severe.

Plywood cars are not only lighter in weight, but painting requirements for maintenance are distinctly less than for metal.

Passenger Cars

Passenger cars formerly used veneers and plywood extensively for interiors, but the demand for increased safety led to the use of all-steel cars, the interiors of which, rather interestingly, were printed or decorated to imitate wood, and the imitations were not particularly convincing. Like most American developments, the transition from wood to steel resembled the swing of the pendulum—all the way.

As a consequence, the cars became so very heavy that, in the latter part of the 1930's, a counter trend set in toward lighter streamlined trains. While there are two distinct schools of design in streamlined trains, one toward the use of aluminum and the other favoring stainless steel, yet they both use veneer and plywood extensively for interiors. There can be no successful argument against the use of steel and other metals for the framework of the cars, as a human safety measure. It is equally logical to use the lighter plywood for other requirements where its strength/weight ratios are favorable, and its appearance and other characteristics are desirable. The new modernistic designs favor the use of the new technique of curved plywood using resin adhesives. Plymetal (page 95), combining the advantages of both steel and metal, can play an important part in

the better designs of the streamlined trains of the future, in fact it is finding substantial use at the present time. Another plywood product that is particularly adaptable to interiors is "Flexwood" (page 90), which can be glued to metal surfaces after the completion of metal fabrication. This provides the strength of metal for safety with the beauty of veneers for pleasing appearance.

Whether the technique of molded plywood, under flexible-bag pressures, will find a useful place in the streamlined train program, as it has in aircraft and boats, remains for the future to demonstrate.

Unit Carriers

The development of a LCL unit, for loading at the factory and assembling on flat cars for shipment, or for the opposite process, dates back to about 1930. These units have had a somewhat checkered career, and it is not yet clear whether they merit an important place in the modern transportation program. It has become quite apparent that their use requires a crane to shift from factory to truck to flat car and the reverse. Some units have been provided with a type of retractable truck wheel for transfer purposes, but without marked success. These units have also been used, more or less, for overseas shipments.

Plywood, on steel framework, is the ideal material for these units, and resin-bonded plywood has proved entirely satisfactory in extensive road tests. With the availability of the exterior grade of Douglas fir plywood, which is thoroughly weather resistant, there seems to be a renewed interest in these LCL units. This applies especially to food products, where the insulating value of double-walled plywood affords far better temperature control than in the earlier types of units. The best results have come from 7/8-inch, 7-ply fir, well anchored to steel frames.

The future use of plywood in these units is not so much a matter of plywood adaptability as it is of the development of an economic place in the transportation program for a unit of this size and convenience.

SPORTING GOODS

Plywood and laminated wood have not been particularly important factors in the making of sporting goods, although the laminated tennis racket and ski have recently attracted attention. In both cases the principle of laminated wood construction has resulted in more uniform and dependable strength in curved and bent members, where solid wood was found to be definitely inferior. Both of these sport-

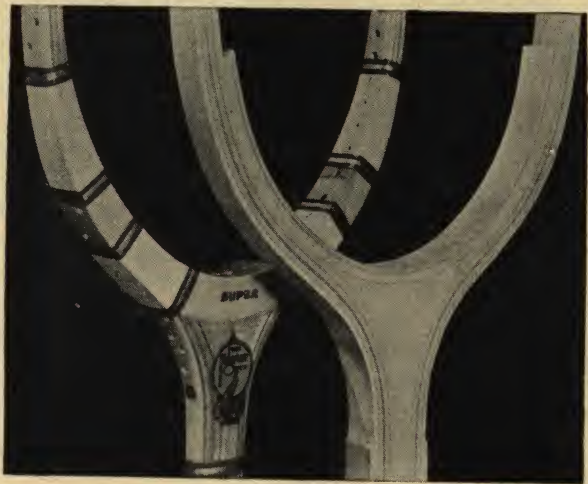
ing products are separately described in the following pages. Amateur boating, with its many ramifications, is distinctly within the sports field, but the outstanding plywood contributions to boat building have been described under the major heading of "Boats and Ships" on pages 230 to 236. Hence no additional information is volunteered here.

There are other similar instances where the making of sporting equipment is described under more comprehensive industrial classifications, such as private airplanes and gliders under aircraft.

Tennis Rackets

Plywood tennis racket frames have practically displaced the solid wood bent type, due largely to the lessened strain on the outer layers of wood fibre at the tip of the racket. The boring and recessing of holes for the strings proved to be a serious weakness which became more evident as the speed of the tennis game increased.

There are two methods of manufacture, one of which is the making of a block of rackets some 12 inches thick in a hydraulic press with multi-directional pressure, using a phenolic-resin film. This method has been successfully employed in England and on the Continent for several years, and a considerable number of such rackets



Courtesy, Fulcrum Co.

Fig. VIII. 26—Laminated tennis racket with Tego-film adhesive.

have been imported into the United States for professional use. This type of construction is shown in Fig. VIII. 26, the right portion showing the laminations and that on the left picturing the finished racket.

The other method is that of assembling single rackets out of strips of ash veneer. After the application of a liquid glue, the ash strips are limber enough so that half a dozen strips can be bent around a metal core, with the ends of the strips forming the center of the handle. The throat is inserted and the whole clamped, with screw and wedge clamps, in several directions, but all within a single plane. These rackets on the clamped metal frame are placed in a kiln at 150°F., for the time necessary to cure the adhesive. In this type of racket all veneer layers are parallel, hence a laminated-wood construction.

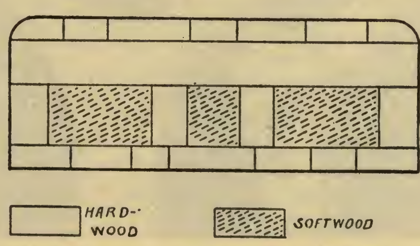
Various adhesives and glues have been used in tennis rackets, but the tendency is strongly toward the resins because of their desirable weather resistance.

Laminated Skis

Winter sports have grown rapidly in popularity in the last few years, and with them the manufacture of the laminated ski. The solid hickory ski is difficult to bend, and curves in solid wood tend not to hold their shape under severe exposure to the elements, the inevitable lot of a ski.

Laminated skis were first made in the Scandanavian countries, where ski transportation is much more than a sport for play boys. In the last few years the making of laminated skis has grown rapidly in the United States, and several factories are now in production.

There are two schools of design in laminated skis, those made of all hickory, and those made with a softer and lighter wood center, where there is no exposure to exterior wear. The all-hickory ski is heavier, with probably slightly greater ultimate strength, and has its advocates. But the lighter type of ski appears to give equally effective service.



Courtesy, S. L. Allen & Co.

Fig. VIII. 27—Cross-section of a laminated ski, at its thickest portion.

A cross-section of the second type of ski is shown in Fig. VIII. 27, where the less dense woods are shaded. The several layers are all of resawn lumber, rather than veneer, and a number of progressive

bonding operations are required. In general, hickory boards, of a nominal one-inch thickness, are glued into blocks, to a thickness that becomes the width of the ski, much as described for plywood cores on page 144, Fig. VI. 7. These blocks are sawn into the desired thickness. If softwood centers are desired, such types of boards are properly located in the block. Since most skis are thicker at the foot plate than at either end, the final central lamination is band sawn to the proper taper, and to provide the crown or arch at the center under the foot plate. All-hickory laminated skis are made by much the same process.

The resin adhesives are best for ski construction, and the clamped forms are usually placed under moderate heat for a matter of several hours. Further mechanical developments are to be expected in such a new industry as that of laminated skis.

Laminated Gun Stocks

Black walnut is the traditional material for gun stocks, both sporting and military, but its growing scarcity and difficult drying technique have repeatedly brought up the question of acceptable substitutes. Laminated stocks of several constructions and a number of species of wood have been suggested and satisfactorily tested. But until the shortage of walnut lumber is more acute, solid gun stocks are likely to continue. There appear to be no difficult problems in the adaptation of laminated wood to gun stocks, and a shift from solid wood would not be surprising at any time.

The laminated gun stock will undoubtedly be more costly, as well as stronger, and it can be made available quickly at any plywood plant, while it takes the better part of a year to produce and season solid black walnut gun stock blanks.

This appears to be an instance where traditional usage is quite dominant in resisting change.

Laminated Fish Rods

Many of the better classes of sportsmen's rods are hexagonal, made of small tapering triangles of the outer or harder section of bamboo. These are glued together, preferably with a resin adhesive, tightly wound with wire or cord, and placed in an oven for resin cure. Such rods, of laminated sections, have more uniform flexure than a conventional bamboo pole, and acquire the additional strength that comes from a laminated, compared with a solid, construction.

Thin laminated veneer has been tried, in place of the solid bamboo triangles, but without marked encouragement.

Other Plywood Applications

There are also other minor sports applications of plywood constructions which do not bulk so large, but are much too numerous to describe. Among the better known that can be mentioned are roller skate wheels, golf club heads and handles, archery equipment, billiard tables and equipment, pin ball machines, ping pong tables, bowling alleys, toys, juvenile games and game boards, card tables and the like.

The new resin-adhesive technique is removing the old plywood handicap, and new plywood adaptations to sports equipment are to be expected.

TRUNKS AND BAGGAGE

Plywood has become established as a desirable material for travelers' baggage. Again the favorable weight/strength factors stand out as an advantage. Undoubtedly the rapid and widespread growth of airplane travel has emphasized the importance of lightweight luggage.

Trunks

Trunks do not seem to be so important an accessory to travel as formerly, and travelers by auto, plane and train appear to prefer a larger number of pieces of hand baggage to the commodious and heavier trunks.

Plywood has long been used in trunks, mostly in the flat form. However, the old barrel-top trunk in the attic undoubtedly had a curved plywood top.

The upright wardrobe trunk, which is more in vogue today, is designed to stand on one end only, to eliminate upsetting its contents. This position is insured, at all times, by the crowned top, which is unquestionably of molded plywood.

Bags and Suitcases

Various types of fibreboard formerly found favor in the manufacture of suitcases, but with the growing availability of thin plywood, a distinct trend can be noted away from fibreboard towards plywood. Before the bending technique of plywood was as well understood as it is today, and antedating the streamlined round corner effect that is so popular, flat plywood sheets were used, nailed and glued to recesses on solid wood corner pieces. These were cov-

ered, inside and outside, with cloth and leather, so that the construction features were not noticeable. However, at the present time, the baggage industry is following the lead of the makers of furniture and radio cabinets, in using the modern hot-bending technique with thin plywood. As a consequence, baggage is stronger and lighter in weight than formerly.

Basswood is favored for luggage plywood, on account of its lightness, but poplar and cottonwood are also used. Thicknesses are 3/32 and ⅛ inch, except in larger units where 3/16 inch may be required for strength and stiffness.

Courtesy, Orenstein Trunk Co.

Fig. VIII. 28—Several types of decorative veneer and plywood luggage.

A recent popular type of airplane luggage has been developed with exposed, but finished, decorative veneer outsides, using leather covering only for corners. This projecting leather, sewed to the plywood, serves not only as reinforcement, but protects the veneer surfaces from excessive rubbing and defacement. An interesting novelty in this exposed-veneer construction is a basket-woven veneer, covered with a molded sheet of cellulose acetate. Several types are shown in Fig. VIII. 28.

It is estimated that the weight of luggage can be reduced from 25 to 40% by the use of plywood, without lessening strength and durability.

MISCELLANEOUS

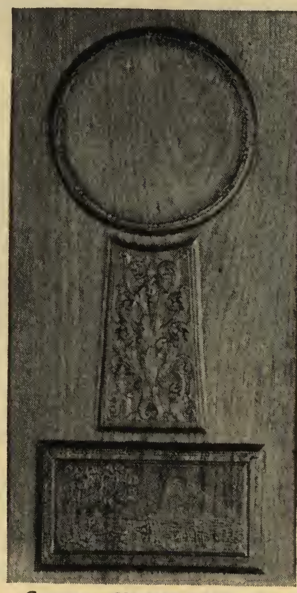
There are a few remaining plywood adaptations worthy of mention that do not fit into the above classifications, and that follow in this final group.

No claim to completeness is made in this enumeration under the section heading, "Plywood in Industry," but an attempt has been made to describe, briefly, the more important applications of plywood to the useful arts.

The tempo of plywood progress is now so rapid that new products and processes are constantly appearing, and any possible listing will need constant revisions.

Carvings of Embossed Plywood

It has been pointed out elsewhere that plywood, under rather more than the normal pressures required for adhesion, can be curved,



Courtesy, Haskelite Mfg. Corp.

Fig. VIII. 29—"Karvart," an embossed plywood carving.

formed, embossed, recessed, and the like. This requires a reverse metal form or matrix, into which the wood veneer may be forced while under heat and pressure. An interesting and attractive example of this is shown in Fig. VIII. 29. Obviously the cost of the matrix or

die can only be absorbed by relatively large quantities. However, when such volume is attainable, the reproduction costs may be very reasonable, and most attractive results can be secured at moderate costs, such as the clock face shown in the illustration mentioned above.

Die-cutting Blocks

This is a well-recognized plywood product of long standing, and is in wide use by those who employ die-cutting knives on paper, cloth, leather and thin metals. These blocks are usually made of multi-ply, hard maple veneer, each layer usually 1/8 inch thick. Block thicknesses may go as high as 9-ply and 17-ply. While most cutting blocks are used flat, there are some unusually exacting requirements where end wood is necessary. In such cases the cutting blocks are made laminated, rather than by standard plywood construction.

The use of resin adhesives has extended the utility of cutting blocks into new fields, where high moisture resistance is important.

Filter Frames

This is an inconspicuous but important plywood application, where the adhesives must be thoroughly waterproof, and the bonds stronger than the wood itself. Many filtering problems require the use of non-metallic and preferably wood frames, in which the corner joints are the points of weakness. Frames cut from plywood sheets are one-piece and overcome the limitations of the ordinary corner joints.

The chemical inertness of the cured phenolic resins, as well as their high resistance to heat and moisture, make them the most advisable adhesive for this exacting work.

Forming Dies

Pairs of dies for forming and shaping thin metal parts under pressure can be made more economically and efficiently from high-density plywood than from any of the metals. It is desirable to have the concave die of a higher density than the convex, because of the heavier duty expected. Side or end wood exposure can be employed according to requirements, either laminated or plywood construction. The densest of these types of plywood is far lighter than any of the available metals, much easier to machine, and much safer to store without the deterioration that comes from the rusting or corroding of metals.

Patterns for Foundries

Plywood is found very useful for thin webs in wooden patterns for metal casting. In fact, plywood permits the making of larger

patterns than are practicable out of solid wood. This is due to the fact that patterns are repeatedly exposed to damp molding sand, which, in substantial areas of solid wood, causes damaging expansion in the pattern. The elimination of shrink and swell in normal plywood construction overcomes this difficulty.

The non-splitting quality of plywood also makes it valuable in patterns which may be severely strained in the tamping of the molding sand.

Resin adhesives, of high moisture resistance, have increased the applicability of plywood to pattern making.

Plywood Trays

The plywood tray which has been popularized by the name "Toastmaster" is a development that was dependent on the use of combined heat and pressure with a resin adhesive. The amount of deformation required would be impossible to attain without heat, and the use of a relatively quick-setting resin was essential to make the production of trays an economic possibility. In a ⅛-inch, 5-ply tray, the complete bonding cycle is a matter of approximately 5

Courtesy, S. E. Overton Co.

Fig. VIII. 30—Walnut plywood tray, recessed, with maple inlay.

minutes, so that an 8-hour production from a six-opening, twin-die press could average over 1000 trays per day.

The general procedure in tray manufacture is to 2-ply the faces and backs while flat, as a reinforcement for the forming operation, which would be likely to split single-ply veneer. These reinforced faces and backs are sanded smooth while they are flat, so that subsequent finish sanding after forming is reduced to a minimum. This sanding also reveals any defects which might make the 2-ply unsuit-

able for further use. The forming operation is the second stage of hot pressing, in pairs of heated metal dies, for which veneer cores and 2-ply can be moistened, if necessary, to reduce the hazard of veneer rupture at the bends. A typical finished inlaid tray is shown in Fig. VIII. 30. The inlay of the lighter colored veneer is made in the veneer face, before 2-plying or sanding.

This same plywood forming technique has been used with equal success in card tables and coffee tables, as shown in Fig. VIII. 31.

Courtesy, Camfield Mfg. Co.

Fig. VIII. 31—Coffee table with recessed plywood top.

Similar formed plywood has been made into square and round plates, as well as into a variety of other useful objects, where the plywood is recessed or made in other than flat shapes.

Saw Handles

The saw handle, with its familiar hand hole, has been made of solid lumber for at least one hundred years. While the gnarly applewood, used for the best-grade handle, is practically unsplittable, this is not true for the other species used. Until resin adhesives were available, the objection to plywood had always been its lack of waterproofness. Casein was used experimentally, but its abrasive action on edge tools was regarded as serious. Resin-bonded plywood is having careful consideration, and exhaustive tests are in progress, with increasingly encouraging results. Serviceability, however, is

only one side of the question, and the other side is the traditional conservatism of the carpenter tradesman, whose father and grandfather used applewood handles. Some consider the violation of such traditions almost criminal, which condition makes changes from solid wood to plywood in the handle field come slowly.

Sewing-machine Covers

The portable sewing-machine cover has been made of plywood for many years. The lightness in weight, the stiffness of the arch construction, and the ease of curving plywood during the bonding operation have made it an advantageous material for this product.

Silent Gears

While wooden peg, cog wheels were highly regarded a hundred years ago for power transmission, it has remained for the present day to develop a type of high-density plywood that can be machined on gear-cutting equipment as efficiently as can metal. The plywood used for gear blanks has the successive veneer layers arranged, not at 90° for alternate layers, but at 15°, 30°, 45°, 60°, etc., around the circle, so that all gear teeth will have a certain proportion of wood grain strength. Such blanks can best be made of 1/30-inch birch veneer, bonded with Tego film, pressed at about 1000 pounds per square inch to a specific gravity of about 1.25, substantially as hard as lignum vitae.

Gears made from such high-density plywood run very quietly and have unusual strength characteristics. Such plywood is practically unaffected by oil or water. This material for gears can be considered in comparison with hard red fibre, with rawhide, and also with plastic fabric combinations. It is extensively used in Europe.

Toilet Seats

Wood has always been the preferred material, and the manfacture of toilet seats has been, and still is, one of the most difficult woodworking problems that has been encountered. While much experimenting has been done with various types of plywood, little success

Courtesy, Brunswick, Balke, Collander Co.

Fig. VIII. 32—"Whalebon-ite" toilet seat.

was achieved until the development of the plastic covered seat, of which a cross-section is shown in Fig. VIII. 32. This particular seat is covered with a rubber composition, vulcanized directly on the

plywood. In any vulcanizing operation, it is imperative that the plywood be as far below 5% M.C. as possible, to prevent the formation of steam pockets during vulcanization.

Other plastic combinations have been used, both in white and colors, but in any thermosetting plastic the internal moisture of plywood will be found to be a hazard.

SUMMARY

A complete list of industrial products that are now or soon will be made from plywood and its allied materials is well nigh impossible. On the one hand, such a list would be tediously long; on the other, it would require rare prophetic skill to foresee even the near-by goals that may be reached by any individual product in this age of rapid industrial progress, when each one, old and new, is being re-evaluated for its useful characteristics.

Plywood offers a wide range of beautiful and attractive effects which are limited by the ingenuity of the artisan and the countless species of trees that grow. It also provides large and useful areas of wood sheeting, and affords advantageous strength/weight ratios for engineering design and development, such as few other materials possess.

In the past, wood and its derivative products have suffered from the "familiarity that breeds contempt." Wood, except as a common construction material, has been the object of very limited technical research, as research is now recognized. The founding of the Forest Products Laboratory at Madison, under the United States Department of Agriculture, did not occur until about 1910, and remarkable progress has been made there in these decades. A few private industrial laboratories have contributed their share. The Wood Industries Division of the American Society of Mechanical Engineers, formed in 1920, was the first scientific attention given to wood problems by a major engineering organization.

Wood, as a raw material, has many valuable qualities but, like all other materials, it also has its individual limitations. Broad foundations have been laid to improve its fire resistance and to increase its durability, both by intelligent methods of wood preservation. When cut into sheets of thin veneer, it can be reassembled into plywood with modern resin adhesives, which are stronger and more durable than the wood itself. The plywood which results adds a new range of valuable characteristics, beyond those inherent in the wood itself, and broadens its application to human comfort and pleasure. Again, impregnation and compression extend its utility

even further. Indeed only the scientific mind can envision what additional improvements are in store.

Plywood will continue to find its major uses in building, including houses and home equipment, in aircraft design, in boat construction, as well as in other fields, but the author is venturesome enough to predict that within the next two decades the applications of plywood to industry will outdistance them all.

QUESTIONS

1. Name some of the principal industrial applications of plywood.
2. What is the historical background of the use of plywood in aircraft construction?
3. Describe laminated spars and their advantages.
4. Outline the method of using plywood ribs and gussets, including a "T" section for attaching skin coverings.
5. In what way can skin coverings be built up in thickness to reduce the number of ribs required?
6. What is the purpose of high-density reinforcing plates, and what is their distinguishing characteristic?
7. Outline several methods of propeller construction in both plywood and laminated wood.
8. What is wrong with the popular term "plastic plane"?
9. Describe the process of making a molded fuselage by the flexible-bag process.
10. What is the process of applying pressure on the outside of the flexible bag, and to what aircraft parts is it best adapted?
11. Discuss differences in strength characteristics between plywood and metal.
12. How are beer barrels made of plywood or laminated wood?
13. Outline the background of the use of plywood in boat construction.
14. Discuss the adaptability of sheet plywood to the building of boat hulls.
15. What are plywood bulkheads in boats and how are they used?
16. Compare the flexible-bag molding process as applied to aircraft and boats.
17. Describe the making of a plywood pontoon.
18. How can plywood be adapted to the making of burial caskets?
19. Discuss the construction uses of plywood as compared with solid lumber.
20. Why is plywood so useful in concrete form work?

21. Describe the making of plywood flooring.
22. Outline the various types of plywood doors.
23. Discuss the problems of prefabricated plywood houses.
24. What is a plywood shook, and how is it braced?
25. Outline one method of making cylindrical drums out of plywood.
26. What are the principal types of furniture, and how does plywood fit into their construction?
27. What are the principal uses of plywood in piano building?
28. How extensively is plywood used in phonograph and radio cabinets?
29. Discuss briefly the uses of plywood in equipment for churches, hospitals, stores, banks and kitchens.
30. What are the opportunities for the use of plywood in automotive vehicles?
31. Describe the construction of a plywood freight car.
32. What are the significant features of a plywood tennis racket?
33. Why is a laminated ski preferable to one made of solid wood?
34. What are other plywood uses in the sports field?
35. Explain the uses of plywood in trunks and suitcases.
36. What are die-cutting blocks, and how are they used?
37. Why is plywood useful in foundry patterns?
38. Describe the process of making plywood trays.
39. What are the advantages of plywood gears?
40. Explain the use of plywood in toilet seats.

SECTION NINE

TABULAR DATA ON PLYWOOD

Wherever possible plywood tabular data have been given in connection with textual description, such as the tables of log scale values, given in Section V on veneer manufacturing. There are a number of tables in the succeeding pages that are too general in character to have any appropriate place in the text, or are of such a suplementary character that they would normally appear in an appendix. These are grouped together in this section, under the following general classifications:

Plywood and Veneer Thickness
Cost Tabulations
Moisture Content Data
Hot-press Data
Engineering Data

Plywood and Veneer Thickness

Conversion relations between common fractions, decimal fractions and millimeters are given in Table IX. 1, including a number of odd fractions that ordinarily are not found in such tables.

The tables that follow indicate, to four places of decimals, the nominal or gross thicknesses of a number of plywood assemblies, including the following types of constructions:

IX. 2—All-veneer constructions, 3-ply, using combinations of different veneer thicknesses, 1/40 to ¼ inch, for faces, backs and cores.

IX. 3—All-veneer constructions, 3- to 25-ply, all plies of the same thickness, 1/90 to 5/16 inch.

IX. 4—All-veneer constructions, 5-ply, using combinations of different veneer thicknesses, 1/40 to ¼ inch, for faces, backs, crossings and cores.

IX. 5—Lumber-core constructions, 5-ply, using lumber cores, ⅜ to ¾ inch, with veneer faces, backs and crossings 1/28 to 1/10 inch.

These will be helpful in determining the best plywood construction for a wide variety of uses.

It is obvious that these are far beyond the precision that may be expected in plywood operations, which is of the order of 1/100 inch. However, in this form they are more conveniently related to the basic thickness data given in Table IX. 1.

Table IX. 1
Common Fractions of an Inch in Decimals and Millimeters

Arranged for Veneer and Plywood Manufacturers

Fractions	*Decimals*	*Millimeters*	*Fractions*	*Decimals*	*Millimeters*
1/100″	.0100	.254	1/5″	.2000	5.08
1/95″	.0105	.267	13/64″	.2031	5.16
1/90″	.0111	.282	3/14″	.2143	5.44
1/85″	.0118	.298	7/32″	.2188	5.56
1/80″	.0125	.318	15/64″	.2344	5.95
1/75″	.0133	.339	1/4″	.2500	6.35
1/70″	.0143	.363	17/64″	.2656	6.75
1/65″	.0154	.391	9/32″	.2813	7.14
1/64″	.0156	.397	19/64″	.2969	7.54
1/60″	.0167	.423	5/16″	.3125	7.94
1/55″	.0182	.462	21/64″	.3281	8.33
1/50″	.0200	.508	11/32″	.3438	8.73
1/48″	.0208	.529	23/64″	.3594	9.13
1/45″	.0222	.564	3/8″	.3750	9.53
1/40″	.0250	.635	25/64″	.3906	9.92
1/35″	.0286	.726	13/32″	.4063	10.32
1/32″	.0313	.794	27/64″	.4219	10.72
1/30″	.0333	.847	7/16″	.4375	11.11
1/28″	.0357	.907	29/64″	.4531	11.51
1/25″	.0400	1.02	15/32″	.4688	11.91
1/24″	.0417	1.06	31/64″	.4844	12.30
1/22″	.0455	1.15	1/2″	.5000	12.70
3/64″	.0469	1.19	33/64″	.5156	13.10
1/20″	.0500	1.27	17/32″	.5313	13.49
1/18″	.0556	1.41	35/64″	.5469	13.89
1/16″	.0625	1.59	9/16″	.5625	14.29
1/15″	.0667	1.69	37/64″	.5781	14.68
1/14″	.0714	1.81	19/32″	.5938	15.08
1/13″	.0769	1.96	39/64″	.6094	15.48
5/64″	.0781	1.98	5/8″	.6250	15.88
1/12″	.0833	2.12	41/64″	.6406	16.27
1/11″	.0909	2.31	21/32″	.6563	16.67
3/32″	.0938	2.38	43/64″	.6719	17.07
1/10″	.1000	2.54	11/16″	.6875	17.46
3/28″	.1071	2.72	45/64″	.7031	17.86
7/64″	.1094	2.78	23/32″	.7188	18.26
1/9″	.1111	2.82	47/64″	.7344	18.65
1/8″	.1250	3.18	3/4″	.7500	19.05
9/64″	.1406	3.57	49/64″	.7656	19.45
1/7″	.1427	3.63	25/32″	.7813	19.84
3/20″	.1500	3.81	51/64″	.7969	20.24
5/32″	.1563	3.97	13/16″	.8125	20.64
1/6″	.1667	4.23	7/8″	.8750	22.23
11/64″	.1719	4.37	15/16″	.9375	23.81
3/16″	.1875	4.76	1″	1.0000	25.40

Suitable allowances must be made for shrinkage, sanding and compression.

Table IX. 2
Gross Thicknesses of Plywood Assemblies
All-veneer Constructions, 3-Ply
(No allowance made for compression or sanding)

3-Ply		Rotary Core Thickness					
Face	*Back*	1/40″	1/28″	1/24″	1/20″	1/16″	1/12″
1/40″	1/40″	.0750	.0857	.0917	.1000	.1125	.1333
	1/28″	.0857	.0964	.1024	.1107	.1232	.1440
	1/24″	.0917	.1024	.1084	.1167	.1292	.1500
1/28″	1/28″	.0964	.1071	.1131	.1214	.1339	.1547
	1/24″	.1024	.1131	.1191	.1274	.1399	.1607
	1/20″	.1107	.1214	.1274	.1357	.1482	.1690
1/24″	1/24″	.1083	.1190	.1250	.1333	.1458	.1667
	1/20″	.1167	.1274	.1333	.1417	.1542	.1750
	1/16″	.1292	.1399	.1459	.1542	.1667	.1875
1/20″	1/20″	.1250	.1357	.1417	.1500	.1625	.1833
	1/16″	.1375	.1482	.1542	.1625	.1750	.1958
	1/12″	.1583	.1690	.1750	.1833	.1958	.2167
1/16″	1/16″	.1500	.1607	.1667	.1750	.1875	.2083
	1/12″	.1718	.1825	.1884	.1968	.2083	.2301
	1/10″	.1875	.1982	.2042	.2125	.2250	.2458
1/12″	1/12″	.1917	.2024	.2084	.2167	.2292	.2500
	1/10″	.2083	.2190	.2250	.2333	.2458	.2667
	1/8″	.2333	.2440	.2500	.2583	.2708	.2917
1/10″	1/10″	.2250	.2357	.2417	.2500	.2625	.2833
	1/8″	.2500	.2607	.2667	.2750	.2875	.3083
	1/7″	.2679	.2786	.2845	.2929	.3054	.3262
1/8″	1/8″	.2750	.2857	.2917	.3000	.3125	.3333
	1/7″	.2929	.3036	.3095	.3179	.3304	.3512
	1/6″	.3167	.3274	.3333	.3417	.3542	.3750
1/7″	1/7″	.3107	.3214	.3274	.3357	.3482	.3691
	1/6″	.3345	.3452	.3512	.3595	.3720	.3929
	3/16″	.3554	.3661	.3720	.3804	.3929	.4137
1/6″	1/6″	.3583	.3690	.3750	.3833	.3958	.4167
	3/16″	.3792	.3899	.3958	.4042	.4167	.4375
	1/4″	.4417	.4524	.4583	.4667	.4792	.5000
3/16″	3/16″	.4000	.4107	.4167	.4250	.4375	.4583
	1/4″	.4625	.4732	.4792	.4875	.5000	.5208
1/4″	1/4″	.5250	.5357	.5417	.5500	.5625	.5833

Continued on next page

Table IX. 2—(*Continued*)
Gross Thicknesses of Plywood Assemblies
All-veneer Constructions, 3-Ply
(No allowance made for compression or sanding)

3-Ply		*Rotary Core Thickness*					
Face	*Back*	1/10″	1/8″	1/7″	1/6″	3/16″	1/4″
1/40″	1/40″	.1500	.1750	.1929	.2167	.2375	.3000
	1/28″	.1607	.1857	.2036	.2274	.2482	.3107
	1/24″	.1667	.1917	.2095	.2333	.2542	.3167
1/28″	1/28″	.1714	.1964	.2143	.2381	.2589	.3214
	1/24″	.1774	.2024	.2203	.2441	.2649	.3274
	1/20″	.1857	.2107	.2286	.2524	.2732	.3357
1/24″	1/24″	.1833	.2083	.2262	.2500	.2708	.3333
	1/20″	.1917	.2167	.2346	.2584	.2792	.3417
	1/16″	.2042	.2292	.2471	.2709	.2917	.3542
1/20″	1/20″	.2000	.2250	.2429	.2667	.2875	.3500
	1/16″	.2125	.2375	.2554	.2792	.3000	.3625
	1/12″	.2333	.2583	.2762	.3000	.3208	.3833
1/16″	1/16″	.2250	.2500	.2679	.2917	.3125	.3750
	1/12″	.2468	.2718	.2897	.3135	.3343	.3968
	1/10″	.2625	.2875	.3054	.3292	.3500	.4125
1/12″	1/12″	.2667	.2917	.3096	.3333	.3542	.4167
	1/10″	.2833	.3083	.3262	.3500	.3708	.4333
	1/8″	.3083	.3333	.3512	.3750	.3958	.4583
1/10″	1/10″	.3000	.3250	.3429	.3667	.3875	.4500
	1/8″	.3250	.3500	.3679	.3917	.4125	.4750
	1/7″	.3429	.3679	.3857	.4095	.4304	.4929
1/8″	1/8″	.3500	.3750	.3929	.4167	.4375	.5000
	1/7″	.3679	.3929	.4107	.4345	.4554	.5179
	1/6″	.3917	.4167	.4345	.4583	.4792	.5417
1/7″	1/7″	.3857	.4107	.4286	.4524	.4732	.5387
	1/6″	.4095	.4345	.4524	.4762	.4970	.5595
	3/16″	.4304	.4554	.4732	.4970	.5179	.5804
1/6″	1/6″	.4333	.4583	.4762	.5000	.5208	.5833
	3/16″	.4542	.4792	.4970	.5208	.5416	.6042
	1/4″	.5167	.5417	.5595	.5833	.6043	.6667
3/16″	3/16″	.4750	.5000	.5179	.5417	.5625	.6250
	1/4″	.5375	.5625	.5804	.6042	.6250	.6875
1/4″	1/4″	.6000	.6250	.6429	.6667	.6875	.7500

Table IX. 3
Gross Thicknesses of Plywood Assemblies
All-veneer Constructions, 3- to 13-Ply

(No allowance made for compression or sanding)
All equal plies of the same thickness, rotary cut

Thickness of Veneer	*Plies*					
	3	5	7	9	11	13
1/90″	.0333	.0556	.0778	.1000	.1222	.1444
1/80″	.0375	.0625	.0875	.1125	.1375	.1625
1/70″	.0429	.0714	.1000	.1286	.1571	.1857
1/64″	.0469	.0781	.1094	.1406	.1719	.2031
1/60″	.0500	.0835	.1167	.1500	.1833	.2167
1/50″	.0600	.1000	.1400	.1800	.2200	.2600
1/48″	.0625	.1042	.1458	.1875	.2292	.2708
1/45″	.0667	.1111	.1556	.2000	.2444	.2889
1/40″	.0750	.1250	.1750	.2250	.2750	.3250
1/35″	.0859	.1429	.2000	.2571	.3143	.3714
1/32″	.0938	.1563	.2188	.2813	.3438	.4063
1/30″	.1000	.1667	.2333	.3000	.3667	.4333
1/28″	.1071	.1786	.2500	.3214	.3929	.4643
1/24″	.1250	.2083	.2917	.3750	.4583	.5417
1/20″	.1500	.2500	.3500	.4500	.5500	.6500
1/18″	.1667	.2778	.3889	.5000	.6111	.7222
1/16″	.1875	.3125	.4375	.5625	.6875	.8125
1/15″	.2000	.3333	.4667	.6000	.7333	.8667
1/14″	.2143	.3572	.5000	.6429	.7857	.9286
5/64″	.2344	.3906	.5469	.7031	.8594	1.0156
1/12″	.2500	.4167	.5833	.7500	.9167	1.0833
3/32″	.2813	.4688	.6563	.8438	1.0313	1.2188
1/10″	.3000	.5000	.7000	.9000	1.1000	1.3000
1/9″	.3333	.5556	.7778	1.0000	1.2222	1.4444
1/8″	.3750	.6250	.8750	1.1250	1.3750	1.6250
1/7″	.4286	.7143	1.0000	1.2857	1.5715	1.8572
5/32″	.4688	.7813	1.0938	1.0463	1.7188	2.0313
1/6″	.5000	.8333	1.1667	1.5000	1.8333	2.1667
3/16″	.5625	.9375	1.3125	1.6875	2.0625	2.4375
7/32″	.6563	1.0938	1.5313	1.9688	2.4063	2.8438
1/4″	.7500	1.2500	1.7500	2.2500	2.7500	3.2500
9/32″	.8438	1.4063	1.9688	2.5313	3.0938	3.6563
5/16″	.9375	1.5625	2.1875	2.8125	3.4375	4.0625

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Table IX. 3—(*Continued*)
Gross Thicknesses of Plywood Assemblies
All-veneer Constructions, 15- to 25-Ply

(No allowance made for compression or sanding)
All equal plies of the same thickness, rotary cut

Thickness of Veneer	*Plies*					
	15	17	19	21	23	25
1/90″	.1667	.1889	.2111	.2333	.2556	.2778
1/80″	.1875	.2125	.2375	.2625	.2875	.3125
1/70″	.2143	.2428	.2714	.3000	.3286	.3571
1/64″	.2344	.2656	.2969	.3281	.3594	.3906
1/60″	.2500	.2833	.3167	.3500	.3833	.4167
1/50″	.3000	.3400	.3800	.4200	.4600	.5000
1/48″	.3125	.3542	.3959	.4375	.4792	.5206
1/45″	.3333	.3778	.4222	.4667	.5111	.5556
1/40″	.3750	.4250	.4750	.5250	.5750	.6250
1/35″	.4286	.4857	.5429	.6000	.6571	.7143
1/32″	.4688	.5313	.5938	.6563	.7188	.7813
1/30″	.5000	.5667	.6333	.7000	.7667	.8333
1/28″	.5357	.6072	.6786	.7500	.8214	.8928
1/24″	.6250	.7083	.7917	.8750	.9583	1.0417
1/20″	.7500	.8500	.9500	1.0500	1.1500	1.2500
1/18″	.8333	.9444	1.0556	1.1667	1.2778	1.3889
1/16″	.9375	1.0625	1.1875	1.3125	1.4375	1.5625
1/15″	1.0000	1.1333	1.2667	1.4000	1.5333	1.6667
1/14″	1.0714	1.2143	1.3572	1.5000	1.6429	1.7857
5/64″	1.1719	1.3281	1.4844	1.6407	1.7970	1.9532
1/12″	1.2500	1.4167	1.5833	1.7500	1.9167	2.0833
3/32″	1.4063	1.5938	1.7813	1.9688	2.1563	2.3438
1/10″	1.5000	1.7000	1.9000	2.1000	2.3000	2.5000
1/9″	1.6667	1.8889	2.1111	2.3333	2.5556	2.7778
1/8″	1.8750	2 1250	2.3750	2.6250	2.8750	3.1250
1/7″	2.1429	2.4286	2.7143	3.0000	3.2857	3.5714
5/32″	2.3438	2.6563	2.9688	3.2813	3.5938	3.9063
1/6″	2.5000	2.8333	3.1667	3.5000	3.8333	4.1667
3/16″	2.8125	3.1875	3.5625	3.9375	4.3125	4.6875
7/32″	3.2813	3.7188	4.1563	4.5938	5.0313	5.4688
1/4″	3.7500	4.2500	4.7500	5.2500	5.7500	6.2500
9/32″	4.2188	4.7813	5.3438	5.9063	6.4688	7.0313
5/16″	5 6875	5.3125	5.9375	6.5625	7.1875	7.8125

Table IX. 4
Gross Thicknesses of Plywood Assemblies, 5-Ply
(No allowance made for compressson or sanding)

5-Ply		*Rotary Core Thickness*						
Face	*Back*	1/28"	1/24"	1/20"	1/16"	1/12"	1/10"	1/8"
Both Crossbands 1/40" Thick								
1/40"	1/40"	.1357	.1417	.1500	.1625	.1833	.2000	.2250
	1/28"	.1464	.1524	.1607	.1732	.1940	.2107	.2357
	1/24"	.1524	.1584	.1667	.1792	.2000	.2167	.2417
1/28"	1/28"	.1571	.1631	.1714	.1839	.2048	.2214	.2464
	1/20"	.1631	.1691	.1774	.1899	.2107	.2274	.2703
	1/16"	.1714	.1774	.1857	.1982	.2190	.2357	.2607
1/24"	1/24"	.1691	.1750	.1833	.1958	.2167	.2333	.2583
	1/20"	.1774	.1833	.1917	.2042	.2250	.2417	.2667
	1/16"	.1899	.1958	.2042	.2167	.2375	.2542	.2792
1/20"	1/20"	.1457	.1917	.2000	.2125	.2333	.2500	.2750
	1/16"	.1982	.2042	.2125	.2250	.2458	.2625	.2875
	1/12"	.2190	.2250	.2333	.2458	.2667	.2833	.3083
Both Crossbands 1/28" Thick								
1/28"	1/28"	.1786	.1845	.1929	.2054	.2262	.2429	.2679
	1/24"	.1845	.1905	.1988	.2113	.2321	.2488	.2738
	1/20"	.1928	.1988	.2071	.2196	.2404	.2571	.2821
1/24"	1/24"	.1905	.1964	.2048	.2173	.2381	.2548	.2798
	1/20"	.1988	.2048	.2131	.2256	.2464	.2631	.2881
	1/16"	.2113	.2173	.2256	.2381	.2589	.2756	.3006
1/20"	1/20"	.2071	.2131	.2214	.2339	.2547	.2714	.2964
	1/16"	.2196	.2256	.2339	.2464	.2672	.2839	.3089
	1/12"	.2404	.2464	.2547	.2672	.2880	.3047	.3297
1/16"	1/16"	.2321	.2381	.2464	.2589	.2797	.2964	.3214
	1/12"	.2529	.2589	.2673	.2798	.3006	.3173	.3423
	1/10"	.2696	.2756	.2839	.2964	.3173	.3339	.3589
Both Crossbands 1/24" Thick								
1/24"	1/24"	.2024	.2083	.2167	.2292	.2500	.2667	.2917
	1/20"	.2107	.2167	.2250	.2375	.2583	.2750	.3000
	1/16"	.2232	.2292	.2375	.2500	.2708	.2875	.3125
1/20"	1/20"	.2190	.2250	.2333	.2458	.2667	.2833	.3083
	1/16"	.2315	.2375	.2458	.2583	.2792	.2958	.3208
	1/12"	.2524	.2583	.2667	.2792	.3000	.3167	.3417
1/16"	1/16"	.2440	.2500	.2583	.2708	.2917	.3083	.3333
	1/12"	.2648	.2708	.2792	.2917	.3125	.3292	.3542
	1/10"	.2815	.2875	.2958	.3083	.3292	.3458	.3708
1/12"	1/12"	.2857	.2917	.3000	.3125	.3333	.3500	.3750
	1/10"	.3024	.3083	.3167	.3293	.3500	.3667	.3917
	1/8"	.3274	.3333	.3417	.3542	.3750	.3917	.4167

Continued on next page

Table IX. 4—(*Continued*)
Gross Thicknesses of Plywood Assemblies, 5-Ply
(No allowance made for compression or sanding)

5-Ply		Rotary Core Thickness						
Face	*Back*	1/12″	1/10″	1/8″	1/7″	1/6″	3/16″	1/4″
Both Crossbands 1/20″ Thick								
1/28″	1/28″	.2548	.2714	.2964	.3143	.3381	.3589	.4214
	1/24″	.2607	.2774	.3024	.3202	.3441	.3649	.4274
	1/20″	.2690	.2857	.3107	.3286	.3524	.3732	.4357
1/24″	1/24″	.2667	.2833	.3083	.3262	.3500	.3708	.4333
	1/20″	.2750	.2917	.3167	.3346	.3584	.3792	.4417
	1/16″	.2875	.3042	.3292	.3471	.3709	.3917	.4542
1/20″	1/20″	.2833	.3000	.3250	.3429	.3667	.3875	.4500
	1/16″	.2958	.3125	.3375	.3554	.3792	.4000	.4625
	1/12″	.3166	.3333	.3583	.3762	.4000	.4208	.4833
1/16″	1/16″	.3083	.3250	.3500	.3679	.3917	.4125	.4750
	1/12″	.3291	.3458	.3708	.3887	.4125	.4333	.4958
	1/10″	.3458	.3625	.3875	.4054	.4292	.4500	.5125
Both Crossbands 1/16″ Thick								
1/28″	1/28″	.2797	.2964	.3214	.3393	.3631	.3839	.4464
	1/24″	.2857	.3024	.3274	.3453	.3691	.3899	.4524
	1/20″	.2940	.3107	.3357	.3536	.3774	.3982	.4607
1/24″	1/24″	.2917	.3083	.3333	.3512	.3750	.3958	.4583
	1/20″	.3000	.3167	.3417	.3596	.3833	.4042	.4667
	1/16″	.3125	.3292	.3542	.3721	.3959	.4167	.4792
1/20″	1/20″	.3083	.3250	.3500	.3679	.3917	.4125	.4750
	1/16″	.3208	.3375	.3625	.3804	.4042	.4250	.4875
	1/12″	.3416	.3583	.3833	.4012	.4250	.4458	.5083
1/16″	1/16″	.3333	.3500	.3750	.3929	.4167	.4375	.5000
	1/12″	.3541	.3708	.3958	.4137	.4375	.4583	.5208
	1/10″	.3708	.3875	.4125	.4304	.4542	.4750	.5375
Both Crossbands 1/12″ Thick								
1/28″	1/28″	.3214	.3381	.3631	.3810	.4048	.4256	.4881
	1/24″	.3273	.3440	.3690	.3869	.4107	.4315	.4940
	1/20″	.3357	.3524	.3774	.3953	.4191	.4399	.5024
1/24″	1/24″	.3333	.3500	.3750	.3929	.4167	.4375	.5000
	1/20″	.3416	.3583	.3833	.4012	.4250	.4458	.5083
	1/16″	.3541	.3708	.3958	.4137	.4375	.4583	.5208
1/20″	1/20″	.3500	.3667	.3917	.4096	.4333	.4542	.5167
	1/16″	.3625	.3792	.4042	.4221	.4459	.4667	.5292
	1/12″	.3833	.4000	.4250	.4429	.4667	.4875	.5500
1/16″	1/16″	.3750	.3917	.4167	.4345	.4583	.4792	.5417
	1/12″	.3958	.4125	.4375	.4554	.4792	.5000	.5625
	1/10″	.4125	.4292	.4542	.4721	.4959	.5167	.5792

Table IX. 5
Gross Thicknesses of Plywood Assemblies, 5-Ply
(No allowance made for compression or sanding)

5-*Ply*		*Lumber Core Thickness*						
Face	*Back*	3/8″	7/16″	1/2″	9/16″	5/8″	11/16″	3/4″
Both Crossbands 1/20″ Thick								
1/28″	1/28″	.5464	.6089	.6714	.7339	.7964	.8589	.9214
	1/24″	.5524	.6149	.6774	.7399	.8024	.8649	.9274
	1/20″	.5607	.6232	.6857	.7482	.8107	.8732	.9357
1/24″	1/24″	.5583	.6208	.6833	.7458	.8083	.8708	.9333
	1/20″	.5667	.6292	.6917	.7542	.8167	.8792	.9417
	1/16″	.5792	.6417	.7042	.7667	.8292	.8917	.9542
1/20″	1/20″	.5750	.6375	.7000	.7625	.8250	.8875	.9500
	1/16″	.5875	.6500	.7125	.7750	.8375	.9000	.9625
	1/12″	.6083	.6708	.7333	.7958	.8583	.9208	.9833
1/16″	1/16″	.6000	.6625	.7250	.7875	.8500	.9125	.9750
	1/12″	.6208	.6833	.7458	.8083	.8708	.9333	.9958
	1/10″	.6375	.7000	.7625	.8250	.8875	.9500	1.0125
Both Crossbands 1/16″ Thick								
1/28″	1/28″	.5714	.6339	.6964	.7589	.8214	.8839	.9464
	1/24″	.5774	.6399	.7024	.7649	.8274	.8899	.9524
	1/20″	.5857	.6482	.7107	.7732	.8357	.8982	.9607
1/24″	1/24″	.5833	.6458	.7083	.7708	.8333	.8958	.9583
	1/20″	.5917	.6542	.7167	.7792	.8417	.9042	.9667
	1/16″	.6042	.6667	.7292	.7917	.8542	.9167	.9792
1/20″	1/20″	.6000	.6625	.7250	.7875	.8500	.9125	.9750
	1/16″	.6125	.6750	.7375	.8000	.8625	.9250	.9875
	1/12″	.6333	.6958	.7583	.8208	.8833	.9458	1.0083
1/16″	1/16″	.6250	.6875	.7500	.8125	.8750	.9375	1.0000
	1/12″	.6458	.7083	.7708	.8333	.8958	.9583	1.0208
	1/10″	.6625	.7250	.7875	.8500	.9125	.9750	1.0375
Both Crossbands 1/12″ Thick								
1/28″	1/28″	.6131	.6756	.7381	.8006	.8631	.9256	.9881
	1/24″	.6191	.6816	.7441	.8066	.8691	.9316	.9941
	1/20″	.6274	.6899	.7524	.8149	.8774	.9399	1.0024
1/24″	1/24″	.6250	.6875	.7500	.8125	.8750	.9375	1.0000
	1/20″	.6333	.6958	.7583	.8208	.8833	.9458	1.0083
	1/16″	.6458	.7083	.7708	.8333	.8958	.9583	1.0208
1/20″	1/20″	.6417	.7042	.7667	.8292	.8917	.9542	1.0167
	1/16″	.6542	.7167	.7792	.8417	.9042	.9667	1.0292
	1/12″	.6750	.7375	.8000	.8625	.9250	.9875	1.0500
1/16″	1/16″	.6667	.7292	.7917	.8542	.9167	.9792	1.0417
	1/12″	.6875	.7500	.8125	.8750	.9375	1.0000	1.0652
	1/10″	.7042	.7667	.8292	.8917	.9542	1.0167	1.0792

Cost Tabulations

The tables that follow in this group relate to the cost of material over a range of yield percentages, and to the percentages of waste that occur with various trim allowances.

The method of derivation and application of Table IX. 6 on trim waste is shown in the footnote below.* It is quite customary in plywood cost computations to base the manufacturing costs on net customers' sizes, although adequate allowances must be made for the total cost of the gross quantities and sizes of raw materials, as is indicated in the example below Table IX. 7.

It can be argued that the percentages of yield and waste in plywood computations should be based on the original amount of material issued. However, in most veneer and plywood operations, the habit of using net customers' sizes as a base has become well established. The use of this method is, therefore, quite important for comparative purposes in this industry.

In Table IX. 8, the resulting cost of veneer, at any estimated yield or waste percentage, is shown, based on the purchase price shown in the left column. Transportation costs can be included in this purchase cost if desired.

In Table IX. 9, a convenient method is suggested for ascertaining glue line costs, on a known cost of the adhesive mixture, and on a spread basis that can be determined by a testing program, as described on pages 167-9 and 336-7.

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*Footnote to Table IX.6 (next page)

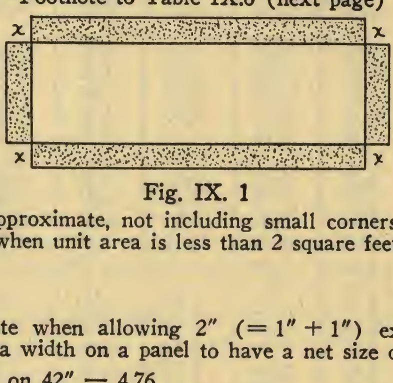

Fig. IX. 1

This method is approximate, not including small corners "x," but the error is appreciable only when unit area is less than 2 square feet.

Method of use

What is the waste when allowing 2″ (= 1″ + 1″) extra length and 1″ (= ½″ + ½″) extra width on a panel to have a net size of 22″ × 42″?

2″ trim on 42″ = 4.76
1″ trim on 22″ = 4.55 = 9.31% waste over net size

What is the waste on a 48″ × 96″ panel, when allowing 1″ trim each on both edges and 1½″ on each end?

2″ trim on 48″ = 4.17
3″ trim on 96″ = 3.13 = 7.30% waste

Table IX. 6
Percentage of Trim Waste
Calculated on Net Sizes Veneer and Plywood

Net Dimension	*Oversize to be Trimmed Off*							
	¼"+¼"	½"+½"	⅝"+⅝"	¾"+¾"	⅞"+⅞"	1"+1"	1¼"+1¼"	1½"+1½"
6"	8.33	16.67	20.82	25.00	....	....	....	....
6½"	7.67	15.38	19.23	23.08	....	....	....	....
7"	7.14	14.28	17.86	21.43	25.00	....	....	....
7½"	6.67	13.33	16.67	20.00	23.33	....	....	....
8"	6.25	12.50	15.63	18.75	21.88	25.00	....	....
8½"	5.88	11.76	14.71	17.65	20.59	23.53	....	....
9"	5.56	11.11	13.89	16.67	19.44	22.22	....	....
9½"	5.26	10.53	13.16	15.79	18.42	21.05	....	....
10"	5.00	10.00	12.50	15.00	17.50	20.00	25.00	....
10½"	4.76	9.52	11.90	14.28	16.67	19.05	23.81	....
11"	4.55	9.09	11.36	13.64	16.00	18.18	22.73	....
11½"	4.35	8.70	10.87	13.04	15.22	17.39	21.74	....
12"	4.17	8.33	10.41	12.50	14.58	16.67	20.83	25.00
13"	3.85	7.69	9.62	11.54	13.46	15.38	19.23	23.08
14"	3.57	7.14	8.93	10.71	12.50	14.28	17.86	21.43
15"	3.33	6.67	8.33	10.00	11.67	13.33	16.67	20.00
16"	3.13	6.25	7.81	9.38	10.94	12.50	15.63	18.75
17"	2.94	5.88	7.35	8.82	10.29	11.76	14.71	17.65
18"	2.78	5.56	6.94	8.33	9.72	11.11	13.89	16.67
19"	2.63	5.26	6.58	7.90	9.21	10.53	13.16	15.79
20"	2.50	5.00	6.25	7.50	8.75	10.00	12.50	15.00
21"	2.38	4.76	5.95	7.14	8.33	9.52	11.90	14.28
22"	2.27	4.55	5.68	6.82	8.00	9.09	11.36	13.64
23"	2.17	4.35	5.43	6.52	7.61	8.70	10.87	13.04
24"	2.08	4.17	5.21	6.25	7.29	8.33	10.41	12.50
26"	1.92	3.85	4.81	5.77	6.73	7.69	9.62	11.54
28"	1.79	3.57	4.46	5.36	6.25	7.14	8.93	10.71
30"	1.67	3.33	4.17	5.00	5.83	6.67	8.33	10.00
32"	1.56	3.13	3.91	4.69	5.47	6.25	7.81	9.38
34"	1.47	2.94	3.68	4.41	5.15	5.88	7.35	8.82
36"	1.37	2.78	3.47	4.17	4.86	5.56	6.94	8.33
38"	1.32	2.63	3.29	3.95	4.61	5.26	6.58	7.90
40"	1.25	2.50	3.13	3.75	4.38	5.00	6.25	7.50
42"	1.19	2.38	2.98	3.57	4.17	4.76	5.95	7.14
44"	1.14	2.27	2.84	3.41	4.00	4.55	5.68	6.82
46"	1.09	2.17	2.72	3.26	3.80	4.35	5.43	6.52
48"	1.04	2.08	2.60	3.13	3.65	4.17	5.21	6.25
54"	.93	1.85	2.31	2.78	3.24	3.70	4.63	5.56
60"	.83	1.67	2.08	2.50	2.91	3.33	4.17	5.00
66"	.72	1.52	1.89	2.27	2.67	3.03	3.79	4.55
72"	.68	1.37	1.74	2.08	2.43	2.78	3.47	4.17
78"	.64	1.28	1.60	1.92	2.24	2.56	3.21	3.85
84"	.60	1.19	1.49	1.79	2.09	2.38	2.98	3.57
90"	.56	1.11	1.39	1.67	1.94	2.22	2.78	3.33
96"	.52	1.04	1.30	1.56	1.82	2.08	2.60	3.13

Footnote on preceding page

Table IX. 7
Gross Veneer Quantities for Net Veneer Requirements in Square Feet

Yield	*Net Requirements, Square Feet*							
100%	1000	1250	1500	2000	2500	3000	3500	4000
↓	Gross Footage to Produce above Net							
97½	1026	1282	1538	2051	2564	3077	3590	4103
95	1053	1316	1579	2105	2632	3158	3684	4211
92½	1081	1351	1622	2162	2703	3243	3784	4324
90	1111	1389	1667	2222	2778	3333	3889	4444
87½	1143	1428	1714	2286	2857	3428	4000	4571
85	1176	1471	1765	2353	2941	3529	4118	4706
82½	1212	1515	1818	2424	3030	3636	4242	4848
80	1250	1563	1875	2500	3125	3750	4375	5000
77½	1290	1613	1935	2581	3226	3871	4516	5161
75	1333	1667	2000	2667	3333	4000	4667	5333
72½	1379	1724	2069	2759	3448	4138	4828	5517
70	1429	1786	2143	2857	3571	4286	5000	5714
67½	1481	1852	2222	2963	3704	4444	5185	5926
65	1538	1923	2308	3077	3846	4615	5385	6154
62½	1600	2000	2400	3200	4000	4800	5600	6400
60	1667	2083	2500	3333	4167	5000	5833	6667
57½	1739	2174	2609	3478	4348	5217	6078	6957
55	1818	2273	2727	3636	4545	5455	6364	7273
52½	1905	2381	2857	3810	4762	5714	6667	7619
50	2000	2500	3000	4000	5000	6000	7000	8000
47½	2105	2632	3158	4211	5263	6316	7368	8421
45	2222	2778	3333	4444	5556	6667	7778	8889
42½	2352	2941	3530	4707	5882	7057	8235	9412
40	2500	3125	3750	5000	6250	7500	8750	10000
37½	2667	3333	4000	5333	6667	8000	9333	10667
35	2857	3571	4286	5714	7143	8571	10000	11429
32½	3077	3846	4615	6154	7692	9231	10769	12308
30	3333	4167	5000	6667	8333	10000	11667	13333

Example: An order requiring 3500 feet net (customer size) is estimated to have a cutting yield of 70% and then a trim waste of 10%. What amount of stock should be issued?

Answer: 90% (yield) of 70% = 63%. In above table 62½% yield requires 5600 gross to produce 3500 feet net.

Table IX. 8
Net Veneer Cost

At Various Yield and Waste Percentages per Thousand Square Feet

Yield →	90%	85%	80%	75%	70%	65%	60%
Waste →	10%	15%	20%	25%	30%	35%	40%
Purchase Price, per 1000 Square Feet							
$ 5.00	$ 5.55	$ 5.88	$ 6.25	$ 6.67	$7.14	$7.69	$ 8.33
5.50	6.11	6.47	6.88	7.33	7.86	8.46	9.17
6.00	6.67	7.06	7.50	8.00	8.57	9.23	10.00
6.50	7.22	7.65	8.13	8.67	9.29	10.00	10.83
7.00	7.78	8.24	8.75	9.33	10.00	10.77	11.67
7.50	8.33	8.82	9.38	10.00	10.71	11.54	12.50
8.00	8.89	9.41	10.00	10.67	11.43	12.31	13.33
8.50	9.44	10.00	10.63	11.33	12.14	13.08	14.16
9.00	10.00	10.59	11.25	12.00	12.86	13.85	15.00
9.50	10.56	11.18	11.89	12.67	13.57	14.62	15.83
10.00	11.11	11.76	12.50	13.33	14.29	15.38	16.67
10.50	11.67	12.35	13.13	14.00	15.00	16.15	17.50
11.00	12.22	12.94	13.75	14.67	15.71	16.92	18.33
11.50	12.78	13.53	14.38	15.33	16.43	17.68	19.17
12.00	13.33	14.12	15.00	16.00	17.14	18.46	20.00
12.50	13.89	14.68	15.63	16.67	17.86	19.23	20.83
13.00	14.44	15.29	16.25	17.33	18.57	20.00	21.67
14.00	15.56	16.47	17.50	18.67	20.00	21.54	23.33
15.00	16.67	17.65	18.75	20.00	21.43	23.08	25.00
16.00	17.78	18.82	20.00	21.33	22.86	24.60	26.67
17.00	18.89	20.00	21.25	22.67	24.29	26.15	28.33
17.50	19.44	20.59	21.88	23.33	25.00	26.92	29.17
18.00	20.00	21.18	22.50	24.00	25.71	27.68	30.00
19.00	21.11	22.35	23.75	25.33	27.14	29.23	31.67
20.00	22.22	23.53	25.00	26.67	28.57	30.77	33.33
21.00	23.33	24.61	26.25	28.00	30.00	32.31	35.00
22.00	24.44	25.88	27.50	29.33	31.43	33.85	36.67
22.50	25.00	26.47	28.13	30.00	32.14	34.62	37.50
23.00	25.56	27.06	28.75	30.67	32.86	35.39	38.33
24.00	26.67	28.24	30.00	32.00	34.29	36.92	40.00
25.00	27.78	29.41	31.25	33.33	35.71	38.46	41.67
27.50	30.56	32.55	34.38	36.67	39.28	42.31	45.83
30.00	33.33	35.29	37.50	40.00	42.86	46.15	50.00
32.50	36.11	38.23	40.83	43.33	46.43	50.00	54.17
35.00	38.89	41.17	43.75	46.67	50.00	53.85	58.33
37.50	41.67	44.12	46.88	50.00	53.57	57.69	62.50
40.00	44.44	47.06	50.00	53.33	57.14	61.54	66.67
42.50	47.22	50.00	53.13	56.67	60.71	65.38	70.83
45.00	50.00	52.94	56.33	60.00	64.28	69.25	75.00
47.50	52.78	55.88	59.38	63.33	67.86	73.01	79.17
50.00	55.56	58.82	62.50	66.67	71.43	76.92	83.33

(*Continued on next page*)

Example: **What will be the cost of veneer required, per 1000 feet *net*, when the flitch cost is $22.50 and the estimated yield 65% (35% waste)?**
Answer: **$34.62.**

Table IX. 8—(*Continued*)
Net Veneer Cost
At Various Yield and Waste Percentages per Thousand Square Feet

Yield →	55%	50%	45%	40%	35%	30%	20%
Waste →	45%	50%	55%	60%	65%	70%	80%
Purchase Price, per 1000 Square Feet							
$5.00	$9.09	$10.00	$11.11	$12.50	$14.29	$16.67	$25.00
5.50	10.00	11.00	12.22	13.75	15.71	18.33	27.50
6.00	10.91	12.00	13.33	15.00	17.14	20.00	30.00
6.50	11.82	13.00	14.44	16.25	18.57	21.67	32.50
7.00	12.73	14.00	15.56	17.50	20.00	23.33	35.00
7.50	13.64	15.00	16.67	18.75	21.43	25.00	37.50
8.00	14.54	16.00	17.78	20.00	22.86	26.67	40.00
8.50	15.45	17.00	18.89	21.25	24.29	28.33	42.50
9.00	16.36	18.00	20.00	22.50	25.71	30.00	45.00
9.50	17.27	19.00	21.11	23.75	27.14	31.67	47.50
10.00	18.18	20.00	22.22	25.00	28.57	33.33	50.00
10.50	19.09	21.00	23.33	26.25	30.00	35.00	52.50
11.00	20.00	22.00	24.44	27.50	31.43	36.67	55.00
11.50	20.91	23.00	25.56	28.75	32.86	38.33	57.50
12.00	21.82	24.00	26.67	30.00	34.29	40.00	60.00
12.50	22.73	25.00	27.78	31.25	35.71	41.67	62.50
13.00	23.64	26.00	28.89	32.50	37.14	43.33	65.00
14.00	25.45	28.00	31.11	35.00	40.00	46.67	70.00
15.00	27.27	30.00	33.33	37.50	42.86	50.00	75.00
16.00	29.09	32.00	35.56	40.00	45.71	53.33	80.00
17.00	30.91	34.00	37.78	42.50	48.57	56.67	85.00
17.50	31.82	35.00	38.89	43.75	50.00	58.33	87.50
18.00	32.73	36.00	40.00	45.00	51.43	60.00	90.00
19.00	34.55	38.00	42.22	47.50	54.29	63.33	95.00
20.00	36.36	40.00	44.44	50.00	57.14	66.67	100.00
21.00	38.18	42.00	46.67	52.50	60.00	70.00	105.00
22.00	40.00	44.00	48.89	55.00	62.86	73.33	110.00
22.50	40.91	45.00	50.00	56.25	64.29	75.00	112.50
23.00	41.82	46.00	51.11	57.50	65.71	76.67	115.00
24.00	43.64	48.00	53.33	60.00	68.57	80.00	120.00
25.00	45.45	50.00	55.56	62.50	71.43	83.33	125.00
27.50	50.00	55.00	61.11	68.75	78.57	91.67	137.50
30.00	54.54	60.00	66.67	75.00	85.71	100.00	150.00
32.50	59.09	65.00	72.22	81.25	92.86	108.33	162.50
35.00	63.64	70.00	77.78	87.50	100.00	116.67	175.00
37.50	68.18	75.00	83.33	93.75	107.14	125.00	187.50
40.00	72.73	80.00	88.89	100.00	114.29	133.33	200.00
42.50	77.27	85.00	95.56	106.25	121.43	141.67	212.50
45.00	81.82	90.00	100.00	112.50	128.57	150.00	225.00
47.50	86.36	95.00	105.56	118.75	135.71	158.33	237.50
50.00	90.91	100.00	111.11	125.00	142.86	166.67	250.00

Example: What will be the cost of veneer required, per 1000 feet *net*, when the flitch cost is $22.50 and the estimated yield 65% (35% waste)?
Answer: $34.62.

Table IX. 9
Cost of Adhesive per 1000 Square Feet, Single Line

(Based on adhesive cost per liquid pound after mixing)

Cost per Pound	*Spread per 1000 Square Feet* 20	25	30	35	40	45	50
$ .010	$ .20	$ .25	$ .30	$ .35	$ .40	$ .45	$ .50
.012	.24	.30	.36	.42	.48	.54	.60
.014	.28	.35	.42	.49	.56	.63	.70
.016	.32	.40	.48	.56	.64	.72	.80
.018	.36	.45	.54	.63	.72	.81	.90
.020	.40	.50	.60	.70	.80	.90	1.00
.022	.44	.55	.66	.77	.88	.99	1.10
.024	.48	.60	.72	.84	.96	1.08	1.20
.026	.52	.65	.78	.91	1.04	1.17	1.30
.028	.56	.70	.84	.98	1.12	1.26	1.40
.030	.60	.75	.90	1.05	1.20	1.35	1.50
.032	.64	.80	.96	1.12	1.28	1.44	1.60
.034	.68	.85	1.02	1.19	1.36	1.53	1.70
.036	.72	.90	1.08	1.26	1.44	1.62	1.80
.038	.76	.95	1.14	1.33	1.52	1.71	1.90
.040	.80	1.00	1.20	1.40	1.60	1.80	2.00
.042	.84	1.05	1.26	1.47	1.68	1.89	2.10
.044	.88	1.10	1.32	1.54	1.76	1.98	2.20
.046	.92	1.15	1.38	1.61	1.84	2.07	2.30
.048	.96	1.20	1.44	1.68	1.92	2.16	2.40
.050	1.00	1.25	1.50	1.75	2.00	2.25	2.50
.052	1.04	1.30	1.56	1.82	2.08	2.34	2.60
.054	1.08	1.35	1.62	1.89	2.16	2.43	2.70
.056	1.12	1.40	1.68	1.96	2.24	2.52	2.80
.058	1.16	1.45	1.74	2.03	2.32	2.61	2.90
.060	1.20	1.50	1.80	2.10	2.40	2.70	3.00
.062	1.24	1.55	1.86	2.17	2.48	2.79	3.10
.064	1.28	1.60	1.92	2.24	2.56	2.88	3.20
.066	1.32	1.65	1.98	2.31	2.64	2.97	3.30
.068	1.36	1.70	2.04	2.38	2.72	3.06	3.40
.070	1.40	1.75	2.10	2.45	2.80	3.15	3.50
.072	1.44	1.80	2.16	2.52	2.88	3.24	3.60
.074	1.48	1.85	2.22	2.59	2.96	3.33	3.70
.076	1.52	1.90	2.28	2.66	3.04	3.42	3.80
.078	1.56	1.95	2.34	2.73	3.12	3.51	3.90
.080	1.60	2.00	2.40	2.80	3.20	3.60	4.00
.082	1.64	2.05	2.46	2.87	3.28	3.69	4.10
.084	1.68	2.10	2.52	2.94	3.36	3.78	4.20
.086	1.72	2.15	2.58	3.01	3.44	3.87	4.30
.088	1.76	2.20	2.64	3.08	3.52	3.96	4.40
.090	1.80	2.25	2.70	3.15	3.60	4.05	4.50
.092	1.84	2.30	2.76	3.22	3.68	4.14	4.60
.094	1.88	2.35	2.82	3.29	3.76	4.23	4.70
.096	1.92	2.40	2.88	3.36	3.84	4.32	4.80
.098	1.96	2.45	2.94	3.43	3.92	4.41	4.90
.100	2.00	2.50	3.00	3.50	4.00	4.50	5.00

Double for 3-ply construction. Multiply by 4 for 5-ply construction. For method of use, see page 169.

Moisture-content Data

This term, as used in woodworking, relates exclusively to the moisture content of the wood, veneer or plywood. Its use in connection with atmospheric humidity is incorrect, and may lead to serious confusion. It is the amount (by weight) of moisture in wood, expressed in percentages of the weight of the oven dry wood.

Its derivation is as follows:

A = Weight of sample in original condition.
B = Weight of sample after oven drying.
C = Loss of weight, or weight of water thus evaporated = A — B; or B = A — C.

$\frac{D}{100}$ = Moisture content (%) of sample

$$= \frac{C}{B} = \frac{A-B}{B} = \frac{A-B}{A-C} = \frac{C}{A-C}.$$

The weight B will be a minimum, and oven drying should be continued until it is reached. Care must be exercised not to char or burn the sample, and it must be weighed immediately, while hot, before any moisture has an opportunity to re-enter.

Table IX. 10 shows percentages of moisture content, when original weight is known (left column) and the loss of weight has been determined by test, which loss of weight is indicated in the lower line of the heading.

Table IX. 11 indicates the humidity of the air necessary to maintain an equilibrium of moisture content in the wood. A graphic chart is shown facing this table. It is obvious if wood, veneer or plywood are not at the equilibrium point, sufficient time must be allowed to reach this equilibrium and items must be so piled that adequate surface exposure is provided.

Atmospheric conditions in any woodworking factory will vary considerably between the open-window stage of the summer months and the closed-window, steam-heat conditions of the winter. There are also distinct differences due to the climatic conditions of the humid south as contrasted with those of the dry, high altitudes of the central states. Many woodworking difficulties resulting from uneven moisture content of the wood can be attributed to failure to stabilize these air conditions in factories where accurate workmanship is essential. This table points the way to proper conditions, which are relatively independent of species of wood.

Wet- and dry-bulb temperatures, required for any percentage of relative humidity of the air, are shown in Table IX. 12. It should be noted that atmospheric conditions in workrooms will vary widely between summer, when there is no artificial heat, and winter, when heat is required. If direct-reading, relative-humidity indicating or recording instruments are used, they must be calibrated for the temperature range in use.

Table IX. 10
Moisture Content Percentages

Computed on oven dry weight basis

Original Weight	*Loss of Weight to Oven Dry* 2	3	4	5	6	7	8	9	10
10	25.0%	42.9%	......						
11	22.2	37.5	......						
12	−20.0	33.3	−50.0%						
13	18.2	−30.0	44.4						
14	16.7	27.3	−40.0						
15	15.4	−25.0	36.4	−50.0%	......				
16	14.3	23.1	33.3	45.4	......				
17	13.3	21.4	30.8	41.7	......				
18	−12.5	−20.0	28.6	38.5	−50.0%	......	......	......	......
19	11.8	18.7	26.7	35.7	46.2	......	......	......	......
20	11.1	17.7	−25.0	33.3	42.9	......	......	......	......
21	10.5	16.7	23.5	31.3	−40.0	−50.0%	......	......	......
22	−10.0	15.8	22.2	29.5	37.5	46.7	......	......	......
23	9.5	−15.0	21.1	27.8	35.3	43.8	......	......	......
24	9.1	14.3	−20.0	26.3	33.3	41.2	−50.0%	......	......
25	8.7	13.6	19.0	−25.0	31.6	38.9	47.1	......	......
26	8.3	13.0	18.2	23.8	−30.0	36.8	44.4	......	......
27	8.0	−12.5	17.3	22.7	28.6	−35.0	42.1	−50.0%	......
28	7.7	−12.0	16.7	21.7	27.3	33.3	−40.0	47.4	......
29	7.4	11.5	−16.0	20.8	26.1	31.8	38.1	−45.0	......
30	7.1	11.1	15.4	−20.0	−25.0	30.4	36.4	42.9	−50.0%
32	6.7	10.3	14.3	18.5	23.1	−28.0	33.3	39.1	45.4
34	6.3	9.7	13.3	17.2	21.4	25.9	30.8	−36.0	41.7
36	5.9	9.1	−12.5	16.1	−20.0	24.1	28.6	33.3	38.5
38	5.6	8.6	11.8	15.1	18.7	22.6	26.7	31.0	35.7
40	5.3	8.1	11.1	14.3	17.6	21.2	−25.0	29.0	33.3
42	−5.0	7.7	10.5	13.5	16.7	−20.0	23.5	27.3	31.3
44	4.8	7.3	−10.0	12.8	15.8	18.9	22.2	25.7	29.4
46	4.5	7.0	9.5	12.2	−15.0	17.9	21.1	24.3	27.8
48	4.3	6.7	9.1	11.6	14.3	17.1	−20.0	23.1	26.3
50	4.2	6.4	8.7	11.1	13.6	16.3	19.1	22.0	−25.0
52	−4.0	6.1	8.3	10.6	13.0	15.6	18.2	20.9	23.8
54	3.8	5.9	−8.0	10.2	−12.5	14.9	17.4	−20.0	22.7
56	3.7	5.7	7.7	9.8	−12.0	14.3	16.7	19.1	21.7
58	3.6	5.5	7.4	9.4	11.5	13.7	−16.0	18.4	20.8
60	3.4	5.3	7.1	9.1	11.1	13.2	15.4	17.6	−20.0
62	3.3	5.1	6.9	8.8	10.7	12.7	14.8	17.0	19.2
64	3.2	4.9	6.7	8.5	10.3	12.3	14.3	16.4	18.5
66	3.1	4.8	6.5	8.2	−10.0	11.9	13.8	15.8	17.9
68	3.0	4.6	6.3	7.9	9.7	11.5	13.3	15.3	17.2

For accurate use of this table it is necessary to bring "original weight" to the whole figure given in left column, by whittling until the weight is correct. Fractional "Loss of Weight" may be easily estimated.

A dash (−) before a figure indicates an exact result.

Formula: Percentage of Moisture Content $= \dfrac{\text{Loss of Weight}}{\text{Original Weight} - \text{Loss of Weight}}$

(*Continued on next page*)

Table IX. 10—(*Continued*)
Moisture Content Percentages

Computed on Oven Dry Weight Basis

Original Weight	*Loss of Weight to Oven Dry*								
	4	5	6	7	8	9	10	11	12
70	6.1	7.7	9.4	11.1	12.9	14.8	16.7	18.6	20.7
72	5.9	7.5	9.1	10.8	−12.5	14.3	16.1	18.0	−20.0
74	5.7	7.2	8.8	10.4	12.1	13.8	15.6	17.5	19.4
76	5.6	7.0	8.6	10.1	11.8	13.4	15.2	16.9	18.8
78	5.4	6.8	8.3	9.9	11.4	13.0	14.7	16.4	18.2
80	5.3	6.7	8.1	9.6	11.1	12.7	14.3	15.9	17.6
82	5.1	6.5	7.9	9.3	10.8	12.3	13.9	15.5	17.1
84	−5.0	6.3	7.7	9.1	10.5	−12.0	13.5	15.1	16.7
86	4.9	6.2	−7.5	8.9	10.3	11.7	13.2	14.7	16.2
88	4.8	6.0	7.3	8.6	−10.0	11.4	12.8	14.3	15.8
90	4.7	5.9	7.1	8.4	9.8	11.1	−12.5	13.9	15.4
92	4.5	5.7	7.0	8.2	9.5	10.8	12.2	13.6	−15.0
94	4.4	5.6	6.8	8.0	9.3	10.6	11.9	13.2	14.6
96	4.3	5.5	6.7	7.9	9.1	10.3	11.6	12.9	14.3
98	4.3	5.4	6.5	7.7	8.9	10.1	11.4	12.6	14.0
100	4.2	5.3	6.4	7.5	8.7	9.9	11.1	12.4	13.6
105	4.0	−5.0	6.0	7.1	8.2	9.4	10.5	11.7	12.9
110	3.8	4.8	5.8	6.8	7.8	8.9	−10.0	11.1	12.2
115	3.6	4.5	5.5	6.5	7.5	8.5	9.5	10.6	11.7
120	3.4	4.3	5.3	6.2	7.1	8.1	9.1	10.1	11.1
125	3.3	4.2	5.0	6.0	6.8	7.8	8.7	9.6	10.6
130	3.2	−4.0	4.8	5.7	6.6	7.4	8.3	9.2	10.2
135	3.0	3.8	4.7	5.5	6.3	7.1	−8.0	8.9	9.8
140	2.9	3.7	4.5	5.3	6.1	6.9	7.7	8.5	9.4
145	2.8	3.6	4.3	5.1	5.8	6.6	7.4	8.2	9.0
150	2.7	3.4	4.2	4.9	5.6	6.4	7.1	7.9	8.7
155	2.6	3.3	4.0	4.7	5.4	6.2	6.9	7.6	8.4
160	2.6	3.2	3.9	4.6	5.3	6.0	6.7	7.4	8.1
165	2.5	3.1	3.8	4.4	5.1	5.8	6.5	7.1	7.8
170	2.4	3.0	3.7	4.3	4.9	5.6	6.3	6.9	7.6
175	2.3	2.9	3.6	4.2	4.8	5.4	6.1	6.7	7.4
180	2.3	2.9	3.4	4.0	4.7	5.3	5.9	6.5	7.1
185	2.2	2.8	3.4	3.9	4.6	5.1	5.7	6.3	6.9
190	2.2	2.7	3.3	3.8	4.4	5.0	5.6	6.1	6.7
195	2.1	2.6	3.2	3.7	4.3	4.8	5.4	6.0	6.6
200	2.0	2.6	3.1	3.6	4.2	4.7	5.3	5.8	6.4

Formula: $\text{Percentage of Moisture Content} = \dfrac{\text{Loss of Weight}}{\text{Original Weight} - \text{Loss of Weight}}$

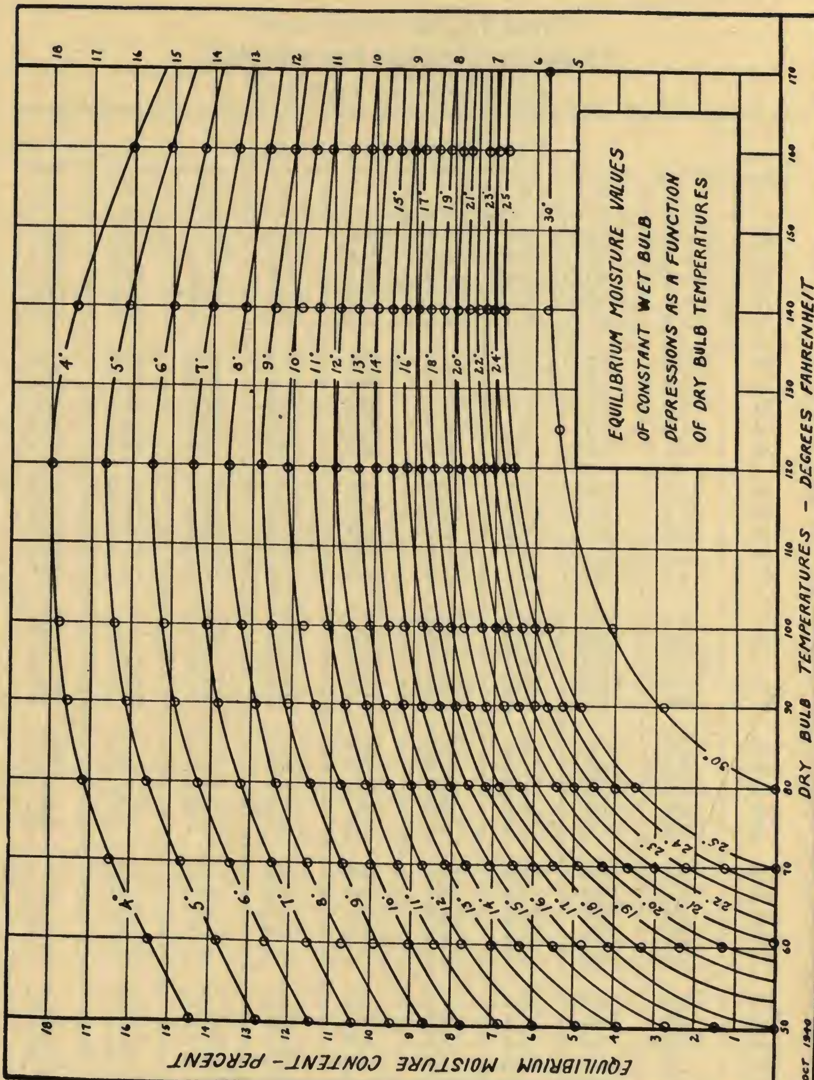

Fig. IX. 2—Chart of equilibrium moisture content.

Table IX. 11
Equilibrium Moisture Content of Wood Products
At various Fahrenheit temperatures, dry- and wet-bulb readings

Dry-bulb Temperatures °F.	Equilibrium Moisture Content of Wood											
	4%	5%	6%	7%	8%	9%	10%	11%	12%	13%	14%	15%
	Wet-bulb Temperatures, Fahrenheit											
50°	34°	36°	38°	39°	40°	41°	42°	43°	44°	45°	46°	46°
55	39	41	42	43	45	46	47	48	49	50	50	51
60	43	44	46	47	49	50	51	52	53	54	55	56
65	46	48	49	51	53	54	56	57	58	59	60	60
70	50	51	53	55	57	58	60	61	63	64	64	65
75	53	55	57	59	61	63	64	66	67	68	69	70
80	56	58	60	63	65	67	69	70	72	73	74	75
85	59	63	64	66	69	71	73	75	76	77	78	79
90	...	65	68	70	73	76	78	79	81	82	83	84
95	...	69	72	75	78	80	82	84	85	87	88	89
100	...	...	76	79	82	85	87	89	90	92	93	94
105	...	...	80	83	86	89	92	94	95	96	98	99
110	...	...	84	88	91	94	96	98	100	101	103	104
115	...	...	...	92	96	99	101	103	105	106	107	109
120	...	...	...	97	100	103	106	108	110	111	112	114
125	...	...	...	102	105	108	111	113	115	116	118	119
130	...	...	...	107	110	113	116	118	120	121	123	124
135	...	...	...	111	115	118	121	123	125	127	128	129
140	...	...	...	116	120	123	126	128	130	132	133	134
145	...	...	...	121	125	128	131	133	135	137	138	139
150	...	...	...	126	130	133	136	138	140	142	143	144
155	...	...	...	131	135	139	142	144	146	147	148	150
160	...	...	...	136	140	144	147	149	151	152	154	155
165	...	...	...	141	145	149	152	154	156	158	159	160
170	...	...	...	146	151	154	157	159	161	163	164	166

Examples:

A What air conditions are required to maintain veneer at 10% M.C. for Tego-film bonding? At 90°F. dry bulb, set humidifier for 78°F. on wet bulb.

B In an oven, where clamped cold-set resin assemblies are placed over night, if M.C. of the wood is to be kept at 12%, and oven heat is 130°F. (dry bulb); set regulator for wet bulb of 120°F.

TABLE IX. 12
Relative Humidity of Air

At various Fahrenheit temperatures dry- and wet-bulb readings

Dry-bulb Readings °F.	*Relative Humidity*												
	40%	45%	50%	55%	60%	65%	70%	75%	80%	85%	90%	95%	100%
	Wet-bulb Readings, Fahrenheit												
50°	40°	41°	42°	43°	44°	45°	45°	46°	47°	48°	48°	49°	50°
55	44	45	46	47	48	49	50	51	52	52	53	54	55
60	48	49	50	51	52	53	54	55	56	57	58	59	60
65	52	53	54	56	57	58	59	60	61	62	63	64	65
70	56	57	59	60	61	62	63	64	66	67	68	69	70
75	60	61	63	64	66	67	68	69	71	72	73	74	75
80	64	65	67	68	70	71	73	74	75	77	78	79	80
85	68	70	71	73	74	76	77	79	80	81	82	84	85
90	71	73	75	77	79	80	82	83	85	86	87	89	90
95	76	77	79	81	83	85	86	88	89	91	92	94	95
100	80	82	83	85	87	89	91	92	94	96	97	99	100
105	83	86	88	90	92	94	95	97	99	100	102	104	105
110	87	90	92	94	96	98	100	102	104	105	107	109	110
115	91	94	97	99	101	103	105	107	108	110	112	113	115
120	95	98	101	103	105	107	109	111	113	115	117	118	120
125	99	102	105	107	109	112	114	116	118	120	122	123	125
130	103	106	109	112	114	116	119	121	123	125	127	128	130
135	107	110	113	116	119	121	123	125	127	129	131	133	135
140	111	115	118	121	123	126	128	130	132	134	136	138	140
145	116	119	122	125	127	130	132	135	137	139	141	143	145
150	119	123	126	129	132	135	137	140	142	144	146	148	150
155	124	127	130	133	136	139	141	144	146	149	151	153	155
160	128	131	135	138	141	144	147	149	151	154	156	158	160
165	132	135	139	142	146	148	151	154	156	159	161	163	165
170	136	140	144	147	150	153	156	159	161	163	165	167	170
175	140	144	147	151	154	157	160	163	166	168	170	172	175
180	144	148	152	156	159	162	165	168	170	173	175	177	180
185	148	152	156	160	163	167	170	172	175	178	180	183	185
190	153	157	161	164	168	171	174	177	180	183	185	187	190
195	157	161	165	169	172	176	179	182	185	187	190	192	195

Example: It is desired to maintain a relative humidity of 75% at 100°F. (dry bulb). Find the intersection of line 100° with column 75%, the answer is 92°, wet bulb.

Hot-press Data

Several mathematical tables are given for convenience in computing conditions that occur in hot-press operations, and that are equally applicable to cold-press work. The areas of circular pistons are shown in Table IX. 13; plywood areas (inches by inches into square inches) are shown in Table IX. 14; and pressure requirements are given in Table IX. 15. Much more extensive area conversion tables (inches by inches into square feet) are given either in Click's or Vermeulen's books, to which reference is made in the Bibliography, pages 352-3.

Conversion tables, **pounds per square inch to kilograms per square centimeter,** are given in Table IX. 16, and will be found of great convenience in translating technical articles from and to foreign languages.

Pressure-temperature equivalents of steam are shown in Table IX. 17.

Table IX. 13
Areas of Circles
(For computing piston and platen pressures)

Diameter	*Area*	*Diameter*	*Area*	*Diameter*	*Area*	*Diameter*	*Area*
4″	12.566″	4¼″	14.186″	4½″	15.904″	4¾″	17.721″
5	19.635	5¼	21.648	5½	23.758	5¾	25.967
6	28.274	6¼	30.680	6½	33.183	6¾	35.785
7	38.485	7¼	41.282	7½	44.179	7¾	47.173
8	50.265	8¼	53.456	8½	56.745	8¾	60.132
9	63.617	9¼	67.201	9½	70.882	9¾	74.662
10	78.540	10¼	82.516	10½	86.590	10¾	90.763
11	95.033	11¼	99.402	11½	103.87	11¾	108.43
12	113.10	12¼	117.86	12½	122.72	12¾	127.68
13	132.73	13¼	137.89	13½	143.14	13¾	148.49
14	153.94	14¼	159.48	14½	165.13	14¾	170.87
15	176.71	15¼	182.65	15½	188.69	15¾	194.83
16	201.06	16¼	207.39	16½	213.82	16¾	220.35
17	226.98	17¼	233.71	17½	240.53	17¾	247.45
18	254.47	18¼	261.59	18½	268.80	18¾	276.12
19	283.53	19¼	291.04	19½	298.65	19¾	306.35
20	314.16	20¼	322.06	20½	330.06	20¾	338.16
21	346.36	21¼	354.66	21½	363.05	21¾	371.54

Table IX. 14
Plywood Areas in Square Inches
To determine specific pressures

Length in Inches	*Width in Inches*										
	18	21	24	27	30	33	36	39	42	45	48
10	180	210	240	270	300	330	360	390	420	450	480
12	216	252	288	324	360	396	432	468	504	540	576
14	252	294	336	378	420	462	504	546	588	630	672
16	288	336	384	432	480	528	576	624	672	720	768
18	324	378	432	486	540	594	648	702	756	810	864
20	360	420	480	540	600	660	720	780	840	900	960
22	396	462	528	594	660	726	792	856	924	990	1056
24	432	504	576	648	720	792	864	936	1008	1080	1152
26	468	546	624	702	780	858	936	1014	1092	1170	1248
28	504	588	672	756	840	924	1008	1092	1176	1260	1344
30	540	630	720	810	900	990	1080	1170	1260	1350	1440
32	576	672	768	864	960	1056	1152	1248	1344	1440	1536
34	612	714	816	918	1020	1122	1224	1326	1428	1530	1632
36	648	756	864	972	1080	1188	1296	1404	1512	1620	1728
38	684	798	912	1026	1140	1254	1368	1482	1596	1710	1824
40	720	840	960	1080	1200	1320	1440	1560	1680	1800	1920
42	756	882	1008	1134	1260	1386	1512	1638	1764	1890	2016
44	792	924	1056	1188	1320	1452	1584	1716	1848	1980	2112
46	828	966	1104	1242	1380	1518	1656	1794	1932	2070	2208
48	864	1008	1152	1296	1440	1584	1728	1872	2006	2160	2304
50	900	1050	1200	1350	1500	1650	1800	1950	2100	2250	2400
52	936	1092	1248	1404	1560	1716	1872	2028	2184	2340	2496
54	972	1134	1296	1458	1620	1782	1944	2106	2268	2430	2592
56	1008	1176	1344	1512	1680	1848	2016	2184	2352	2520	2688
58	1044	1218	1392	1566	1740	1914	2088	2262	2436	2610	2784
60	1080	1260	1440	1620	1800	1980	2160	2340	2520	2700	2880
62	1116	1302	1488	1674	1860	2046	2232	2418	2604	2790	2976
64	1152	1344	1536	1728	1920	2112	2304	2496	2688	2880	3072
66	1188	1386	1584	1782	1980	2178	2376	2574	2772	2970	3168
68	1224	1428	1632	1836	2040	2244	2448	2652	2856	3060	3264
70	1260	1470	1680	1890	2100	2310	2520	2730	2940	3150	3360
72	1296	1512	1728	1944	2160	2376	2592	2808	3024	3240	3456
74	1332	1554	1776	1998	2220	2442	2664	2886	3108	3330	3552
76	1368	1596	1824	2052	2280	2508	2736	2964	3192	3420	3648
78	1404	1638	1872	2106	2340	2674	2808	3042	3276	3510	3744
80	1440	1680	1920	2160	2400	2640	2880	3120	3360	3600	3840
82	1476	1722	1968	2214	2460	2706	2952	3198	3444	3690	3936
84	1512	1764	2016	2268	2520	2772	3024	3276	3528	3780	4032
86	1548	1806	2064	2322	2580	2838	3096	3354	3612	3870	4128
88	1584	1848	2112	2376	2640	2904	3168	3432	3696	3960	4224
90	1620	1890	2160	2430	2700	2970	3240	3510	3780	4050	4320
92	1656	1932	2208	2484	2760	3036	3312	3588	3864	4140	4416
94	1692	1974	2256	2538	2820	3102	3384	3666	3948	4230	4512
96	1728	2016	2304	2592	2880	3168	3456	3744	4032	4320	4608
98	1764	2058	2352	2646	2940	3234	3528	3822	4116	4410	4704
100	1800	2100	2400	2700	3000	3300	3600	3900	4200	4500	4800
102	1836	2142	2448	2754	3060	3366	3672	3978	4284	4590	4896
104	1872	2184	2496	2808	3120	3432	3744	4056	4368	4680	4992
106	1908	2226	2544	2862	3180	3498	3816	4134	4452	4770	5088
108	1944	2268	2592	2916	3240	3564	3888	4212	4536	4860	5184
110	1980	2310	2640	2970	3300	3630	3960	4290	4620	4950	5280
112	2016	2352	2688	3024	3360	3696	4032	4368	4704	5040	5376
114	2052	2394	2736	3078	3420	3762	4104	4446	4788	5130	5472
116	2088	2436	2784	3132	3480	3828	4176	4524	4872	5220	5568
118	2124	2478	2832	3186	3540	3894	4248	4602	4956	5310	5664
120	2160	2520	2880	3240	3600	3960	4320	4680	5040	5400	5760

Table IX. 15
Plywood Pressures

Specific pressure of 100 pounds per square inch

Plywood Area Sq. In.	*Diameter and Number of Press Pistons*						
	One 8″	*One 10″*	*One 12″*	*One 14″*	*One 16″*	*Two 8″*	*Two 10″*
	Pump Pressure Required, Lb. Sq. In.						
100	199	127	88	65	50	99	64
200	398	255	177	130	99	199	127
300	597	382	265	195	149	298	191
400	796	509	354	260	199	398	255
500	995	637	442	325	249	497	318
600	1194	764	531	390	298	597	382
700	1393	891	619	455	348	696	446
800	1592	1019	707	520	398	796	509
900	1790	1146	796	585	448	895	573
1000	1989	1273	884	650	497	995	637
1100	2188	1401	973	715	547	1094	700
1200	2387	1528	1061	780	597	1194	764
1300	2586	1655	1149	844	647	1293	828
1400	2785	1782	1238	909	696	1393	891
1500	2984	1910	1326	974	746	1492	955
1600	3183	2037	1415	1039	796	1592	1019
1700	3382	2164	1503	1104	846	1691	1082
1800	3581	2292	1592	1169	895	1790	1146
1900	3780	2419	1680	1234	945	1890	1206
2000	3979	2546	1768	1299	995	1989	1273
2100	4178	2674	1857	1364	1045	2089	1337
2200	4377	2801	1945	1429	1094	2188	1401
2300	4576	2928	2034	1494	1144	2288	1464
2400	4775	3056	2122	1559	1194	2387	1528
2500	4974	3183	2211	1624	1244	2487	1592
2600	5172	3310	2299	1689	1293	2586	1655
2700	....	3438	2387	1754	1343	2686	1719
2800	....	3565	2476	1819	1393	2785	1782
2900	....	3692	2564	1884	1442	2885	1846
3000	....	3820	2653	1949	1492	2984	1910
3100	....	3947	2741	2014	1542	3084	1973
3200	....	4074	2829	2079	1592	3183	2037
3300	....	4202	2918	2144	1641	3283	2101
3400	....	4329	3006	2209	1691	3382	2164
3500	....	4456	3095	2274	1741	3481	2228
3600	....	4584	3183	2339	1791	3581	2292
3700	....	4711	3272	2404	1840	3680	2355
3800	....	4838	3360	2468	1890	3780	2419
3900	....	4965	3448	2533	1940	3879	2483
4000	....	5093	3537	2598	1990	3979	2546
4100			3625	2663	2039	4078	2610
4200			3714	2728	2089	4178	2674
4300			3802	2793	2139	4277	2737
4400			3890	2858	2189	4377	2801
4500			3979	2923	2238	4476	2865
4600			4067	2988	2288	4576	2928
4700			4156	3053	2338	4675	2992
4800			4244	3118	2388	4775	3056
4900			4333	3183	2437	4874	3119
5000			4421	3248	2487	4974	3183

When
Pump Area = A
Pump Pressure = B
Plywood Area = C
Ply'd Pressure = D

Then
$A \times B = C \times D$

$$B = \frac{C \times D}{A} = 100\frac{C}{A}$$

For higher specific pressures, multiply pump pressures as follows: 150 by 1.5; 200 by 2.0; 250 by 2.5; 300 by 3.0; etc.

Table IX. 16

Tensile Strength Conversion Table

5 Lb. per sq. in. = 0.352 Kg. per sq. cm.
10 " " " " = 0.703 " " " "
15 " " " " = 1.055 " " " "
20 " " " " = 1.406 " " " "

Lb. Sq. In.	*Kg. Sq. Cm.*	*Lb. Sq. In.*	*Kg. Sq. Cm.*	*Lb. Sq. In.*	*Kg. Sq. Cm.*	*Lb. Sq. In.*	*Kg. Sq. Cm.*
....	......	1000	70.307	2000	140.61	3000	210.92
25	1.7577	1025	72 065	2025	142.37	3025	212.68
50	3.5154	1050	73.822	2050	144.13	3050	214.44
75	5.2730	1075	75.580	2075	145.89	3075	216.19
100	7.0307	1100	77.338	2100	147.65	3100	217.95
125	8.7884	1125	79.096	2125	149.40	3125	219.71
150	10.546	1150	80.853	2150	151.16	3150	221.47
175	12.304	1175	82.611	2175	152.92	3175	223.23
200	14.061	1200	84.369	2200	154.68	3200	224.98
225	15.819	1225	86.127	2225	156.43	3225	226.74
250	17.577	1250	87.884	2250	158.19	3250	228.50
275	19.334	1275	89.642	2275	159.95	3275	230.26
300	21.092	1300	91.399	2300	161.71	3300	232.01
325	22.850	1325	93.157	2325	163.46	3325	233.77
350	24.607	1350	94.914	2350	165.22	3350	235.53
375	26.365	1375	96.672	2375	166.98	3375	237.29
400	28.123	1400	98.430	2400	168.74	3400	239.04
425	29.880	1425	100.19	2425	170.49	3425	240.80
450	31.638	1450	101.95	2450	172.25	3450	242.56
475	33.396	1475	103.70	2475	174.01	3475	244.32
500	35.154	1500	105.46	2500	175.77	3500	246.08
525	36.911	1525	107.22	2525	177.53	3525	247.83
550	38.669	1550	108.98	2550	179.28	3550	249.59
575	40.427	1575	110.73	2575	181.04	3775	251.35
600	42.184	1600	112.49	2600	182.80	3600	253.11
625	43.942	1625	114.25	2625	184.56	3625	254.86
650	45.700	1650	116.01	2650	186.31	3650	256.62
675	47.457	1675	117.76	2675	188.07	3675	258.38
700	49.215	1700	119.52	2700	189.83	3700	260.14
725	50.973	1725	121.28	2725	191.59	3725	261.89
750	52.730	1750	123.04	2750	193.34	3750	263.65
775	54.488	1775	124.80	2775	195.10	3775	265.41
800	56.246	1800	126.55	2800	196.86	3800	267.17
825	58.003	1825	128.31	2825	198.62	3825	268.92
850	59.761	1850	130.07	2850	200.38	3850	270.68
875	61.519	1875	131.83	2875	202.13	3875	272.44
900	63.276	1900	133.58	2900	203.89	3900	274.20
925	65.034	1925	135.34	2925	205.65	3925	275.96
950	66.792	1950	137.10	2950	207.41	3950	277.71
975	68.549	1975	138.86	2975	209.16	3975	279.47

(*Continued on next page*)

Table IX. 16—(*Continued*)

Tensile Strength Conversion Table

5 Lb. per sq. in. = 0.352 Kg. per sq. cm.
10 " " " " = 0.703 " " " "
15 " " " " = 1.055 " " " "
20 " " " " = 1.406 " " " "

Lb. Sq. In.	*Kg. Sq. Cm.*	*Lb. Sq. In.*	*Kg. Sq. Cm.*	*Lb. Sq. In.*	*Kg. Sq. Cm.*	*Lb. Sq. In.*	*Kg. Sq. Cm.*
4000	281.23	5000	351.54	6000	421.84	7000	492.15
4025	282.99	5025	353.29	6025	423.60	7025	493.91
4050	284.74	5050	355.05	6050	425.36	7050	495.67
4075	286.50	5075	356.81	6075	427.12	7075	497.42
4100	288.26	5100	358.57	6100	428.87	7100	499.18
4125	290.02	5125	360.32	6125	430.63	7125	500.94
4150	291.77	5150	362.08	6150	432.39	7150	502.70
4175	293.53	5175	363.84	6175	434.15	7175	504.45
4200	295.29	5200	365.60	6200	435.90	7200	506.21
4225	297.05	5225	367.35	6225	437.66	7225	507.97
4250	298.81	5250	369.11	6250	439.42	7250	509.73
4275	300.56	5275	370.87	6275	441.18	7275	511.48
4300	302.32	5300	372.63	6300	442.94	7300	513.24
4325	304.08	5325	374.39	6325	444.69	7325	515.00
4350	305.84	5350	376.14	6350	446.45	7350	516.76
4375	307.59	5375	377.90	6375	448.21	7375	518.52
4400	309.35	5400	379.66	6400	449.97	7400	520.27
4425	311.11	5425	381.42	6425	451.72	7425	522.03
4450	312.87	5450	383.17	6450	453.48	7450	523.79
4475	314.62	5475	384.93	6475	455.24	7475	525.55
4500	316.38	5500	386.69	6500	457.00	7500	527.30
4525	318.14	5525	388.45	6525	458.75	7525	529.06
4550	319.90	5550	390.20	6550	460.51	7550	530.82
4575	321.66	5575	391.96	6575	462.27	7575	532.58
4600	323.41	5600	393.72	6600	464.03	7600	534.33
4625	325.17	5625	395.48	6625	465.78	7625	536.09
4650	326.93	5650	397.24	6650	467.54	7650	537.85
4675	328.69	5675	398.99	6675	469.30	7675	539.61
4700	330.44	5700	400.75	6700	471.06	7700	541.37
4725	332.20	5725	402.51	6725	472.82	7725	543.12
4750	333.96	5750	404.27	6750	474.57	7750	544.88
4775	335.72	5775	406.02	6775	476.33	7775	546 64
4800	337.47	5800	407.78	6800	478.09	7800	548.40
4825	339.23	5825	409.54	6825	479.85	7825	550.15
4850	340.99	5850	411.30	6850	481.60	7850	551.91
4875	342.75	5875	413.05	6875	483.36	7875	553.67
4900	344.50	5900	414.81	6900	485.12	7900	555.43
4925	346.26	5925	416.57	6925	486.88	7925	557.18
4950	348.02	5950	418.33	6950	488.63	7950	558.94
4975	349.78	5975	420.09	6975	490.39	7975	560.70

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Table IX. 17
Pressure-temperature Equivalents of Saturated Steam at Sea Level

Gauge Pressure		Absolute Pressure	Temperature	
Lb. per Sq. In.	*Kg. per Sq. Cm.*	*Atmospheres*	°C.	°F.
0	0.	1.00	100.0	212.0
5	0.352	1.34	108.4	227.1
10	0.703	1.68	115.2	239.4
15	1.055	2.02	121.0	249.8
20	1.406	2.36	126.0	258.8
22	1.547	2.50	127.8	261.2
24	1.687	2.63	129.6	265.3
26	1.828	2.77	131.3	268.3
28	1.968	2.90	132.9	271.2
30	2.109	3.04	134.5	274.1
32	2.250	3.18	136.0	276.8
34	2.390	3.31	137.4	279.3
36	2.531	3.45	138.8	281.8
38	2.671	3.58	140.2	284.4
40	2.812	3.72	141.5	286.7
42	2.953	3.86	142.8	289.0
44	3.093	3.99	144.0	291.2
46	3.234	4.13	145.3	293.5
48	3.374	4.26	146.4	295.5
50	3.515	4.40	147.6	297.7
52	3.656	4.54	148.7	299.7
54	3.796	4.67	149.8	301.6
56	3.937	4.81	150.9	303.6
58	4.077	4.94	151.9	305.4
60	4.218	5.08	153.0	307.4
62	4.359	5.22	154.0	309.2
64	4.499	5.35	154.9	310.8
66	4.640	5.49	155.9	312.6
68	4.780	5.62	156.8	314.2
70	4.921	5.76	157.8	316.0
72	5.062	5.90	158.7	317.7
74	5.202	6.03	159.6	319.3
76	5.343	6.17	160.5	320.9
78	5.483	6.30	161.3	322.3
80	5.624	6.44	162.1	323.8
85	5.976	6.78	164.2	327.6
90	6.327	7.12	166.2	331.2
95	6.679	7.46	168.1	334.6
100	7.031	7.80	169.9	337.8
105	7.382	8.14	171.7	341.1
110	7.734	8.48	173.4	344.1
115	8.085	8.82	175.1	347.2
120	8.437	9.16	176.7	350.1
125	8.788	9.50	178.3	352.9
130	9.140	9.84	179.8	355.6
135	9.491	10.18	181.3	358.3
140	9.843	10.52	182.7	360.9
145	10.194	10.86	184.1	363.4
150	10.546	11.20	185.5	365.9
155	10.897	11.54	186.8	368.2
160	11.249	11.88	188.1	370.6
165	11.600	12.22	189.4	372.9
170	11.952	12.56	190.7	375.3
175	12.303	12.90	191.9	377.4
180	12.655	13.24	193.1	379.6
185	13.006	13.58	194.3	381.7
190	13.358	13.92	195.4	383.7
195	13.709	14.26	196.6	385.9
200	14.061	14.60	197.7	387.9

NOTE: For quick conversion from common to metric units (accurate to 0.5%), multiply pounds per square inch by 0.07 to convert to kilograms per square centimeter.

1 Atmosphere = 14.7 lb. per sq. in. = 1.0333 kg. per sq. cm.

From *Rubber Handbook*, by permission of R. T. Vanderbilt Co.

Engineering Data

The following tables were prepared by the Forest Products Laboratory. The results are based on tests of over 30 species. In general, 8 thicknesses of plywood, ranging from 1/10 to ½ inch, were tested. Most of the tests were on panels composed of three plies of equal thickness, with all plies of the same species and with the grain of successive plies at right angles. In addition, tests were made on plywood of various numbers of plies, having different ratios between core and total panel thickness, having the plies glued at angles other than 90° with each other, and on plywood in which the core and the faces were not of the same species.

Tension Tests

Table IX. 18 shows the tensile strength parallel to the grain of the faces of 3-ply wood of various common veneer species and the approximate strength of single-ply wood. The strength figures, given in pounds per square inch, correspond to the moisture contents listed. The test specimens used to obtain these values were 3 inches wide by 12 inches long, the central portion being trimmed down to a width of approximately 1 inch. They were held by ordinary flat grips and were tested in direct tension to rupture. The tensile strength is the average stress over the section at failure.

Shrinkage

The shrinkage of plywood varies with the species, the ratio of ply thickness, the number of plies, and the combination of species. In order to obtain a general average, the Forest Products Laboratory ran several hundred shrinkage tests on varied combinations of species and thicknesses in which 3-ply panels were brought from a soaked to an oven-dry condition. The species included in the tests were mahogany, birch, yellow poplar, basswood, red gum, chestnut, tupelo gum, elm, sugar (hard) maple, black walnut, Spanish cedar, and spruce. The average shrinkage from the soaked to oven-dry condition was about 0.45 of 1 per cent parallel to the face grain and 0.67 of 1 per cent perpendicular to the face grain, with ranges of 0.2 to 1 per cent and 0.3 to 1.2 per cent, respectively. It is not unlikely that certain combinations of some other species may give wider ranges than these.

Bending and Splitting Tests

The results of the bending tests are given in Table IX. 19. The strength values correspond to the moisture contents given. As a rule, bending tests were made on specimens measuring 5 by 12 inches, al-

though some of the thinner specimens were cut to a length of 6 inches. The pieces were loaded as a column, with the greater dimension vertical. In half of the tests the grain of the faces was parallel to the direction of application of the load, and in half it was perpendicular to it. The ends of the test specimens were rounded in approximately a semi-circle. Deflections were measured at the center of the panel. The product of the load and the corresponding deflection was recorded as the bending moment. Like the modulus of rupture in bending, the column-bending modulus is not a true stress existing in the fibres at the instant of failure. It is merely a measure of the magnitude of the external bending moment that a piece of plywood can withstand before it fails.

A comparison of the relative resistance to splitting of various 3-ply panels will also be found in Table IX. 19. For splitting tests square pieces 3¼ by 3¼ inches were used. Upon the center of the test piece a conical spear was first dropped from a height of one-half inch. The spear was 8 inches long and 2 inches in diameter at the upper end and (with the shaft) weighed 11.22 pounds. Carrying the test piece upon its point it was then dropped from increasing heights until failure due to splitting occurred. The successive increment change in height of drop was one-half inch.

Effect of Increasing Number of Plies

Table IX. 20 gives a comparison of strength characteristics in birch plywood of 3-, 5-, 7- and 9-ply constructions of the same total thickness. The strength factors parallel to the face grain show declines as the number of plies increase; while those perpendicular to the face grain increase up to 7-ply, and then decrease. The splitting resistance, compared to 3-ply of the same total thickness, shows remarkable increases.

Variations in Core Density

Table IX. 21 shows that the strength values of plywood parallel to the grain of the faces are practically the same for 3-ply wood having a core of dense wood as for plywood having a core of light wood. The strength values across the grain of the faces are, however, very much less for the plywood with core of low density. In other words, the strength values of 3-ply wood parallel to the grain of the faces are almost entirely determined by the strength values of the face material, and the strength values across the grain of the faces are very largely determined by the strength values of the core species.

Effect of Veneer Cutting Methods

A special series of tests was made to determine the effect of the method of cutting veneer on the strength of plywood panels made from each. Detailed results are presented in Table IX. 22, and the general conclusions are as follows:

1. The effect of the method of cutting on the strength of plywood depends on the species cut, although in general, the effect, as shown by the bending and tension tests, is not great.
2. Of the three methods of cutting, the sawed and sliced material, for the species tested, gave the more similar results. The commercial white ash, sugar maple, and yellow poplar panels cut by these methods were slightly superior in bending and tensile strength to the rotary-cut panels.
3. For birch, the panels of rotary-cut veneer were slightly superior in bending and tensile strength to panels of either sawed or sliced veneer.
4. For the species tested, with the possible exception of the African mahogany, panels of sawn veneer twist less than panels of either sliced or rotary-cut veneer.
5. With the exception of birch the results show little difference in the twisting of panels of sliced or rotary-cut veneer.

Weights of Veneer

For the convenient calculation of the weight of veneer and plywood, Table IX. 23 has been prepared. This table presents the weights, per square foot, of veneer of various thicknesses and species, at the average air-dry moisture conditions shown in the second column. The weight of blood-albumin glue per square foot and the weight of a typical casein glue (Certus) per square foot are also given, so that it is possible to calculate the average weight of any plywood made up of the species listed and using blood or casein glue. This is done simply by adding together the weights of the individual plies and the weight of the glue, which is obtained by multiplying the weight of the glue per square foot by the number of glue lines in the plywood. This number is always one less than the number of plies.

Thickness Factors Compared to Birch

Table IX. 24 gives a number of factors that are of value in selecting the thickness and species of the plies for a 3-ply panel.

The thickness factor (K_s) is used to obtain the thickness of a ply of any species having the same total bending strength as a given ply of birch. It is arrived at as follows:

The strength of any structural member is determined either by the

direct load it can sustain or the bending moment it can resist without failure. In plywood the latter factor is the better criterion of strength. If we denote the maximum bending moment of a strip of 3-ply wood 1 inch wide and of thickness d_1 by M_1 and the stress at failure S_1 (column-bending modulus), then $M_1 = \frac{S_1 d_1^2}{6}$.

Similarly, the strength of another strip of a different species will be denoted by M_2, its stress at failure S_2, and thickness d_2. By a proper selection of thickness d_2 the second strip may be made to withstand the same maximum bending moment, so that $M_2 = M_1$ or $S_2 d_2^2 = S_1 d_1^2$. From this the desired thickness $d_2 = d_1 \sqrt{\frac{S_1}{S_2}}$. Taking d_1 as the unit of thickness of a birch plywood strip and expressing the maximum stresses in percentage of birch, we have $d_2 = \sqrt{\frac{100}{S_2}}$ or, in general, $K_s = \sqrt{\frac{100}{S}}$ where K_s is the thickness of the plywood, whose column-bending modulus corresponds to S and whose total bending strength, given by the bending moment, is the same as that of birch plywood of thickness unity.

The same reasoning also applies to single plies, so that K_s may be used to get the thickness of a single ply, which will give the same total bending strength as a birch ply of thickness unity. For example, for yellow poplar $K_s = 1.31$, and a ply of this species, $1.31 \times 1/16 = 0.082$ inch, is equivalent in strength in bending to a birch ply 1/16 inch thick.

By way of explanation it must be understood that unit bending strength refers to a maximum stress such as the modulus of rupture, or the column-bending modulus, while total bending strength refers to the load or bending moment a beam can sustain or the bending moment a column can sustain.

It should be kept in mind that these factors will doubtless be modified somewhat by further tests.

The thickness factor (K_w) is used to obtain the thickness of a ply of any species equal in weight to a ply of yellow birch of given thickness. It is obtained by simply dividing the density of birch by the density of the species for which the thickness is desired. The density data used in computing K_w are the same as that given in United States Department of Agriculture Bulletin 556, *Mechanical Properties of Woods Grown in the United States.* The weight of the glue in the plywood is neglected.

For yellow poplar, for example, the thickness of a ply equal in weight to a 1/16-inch ply of birch is $1.54 \times 1/16 = 0.096$ inch.

Table IX. 18
Tensile Strength of Plywood and Veneer

(Data by U. S. Forest Products Laboratory)

Species	*Number of Tests*	*Moisture at Test*	*Specific Gravity*[1] *of Plywood*	*Tensile Strength*[2] *of Three-ply Wood Parallel to Grain of Faces*	*Tensile Strength*[3] *of Single-ply Veneer— 1½ × (d)*
		Per Cent		*Pounds per square inch*	*Pounds per square inch*
	(a)	(b)	(c)	(d)	(e)
Ash, black	120	9.1	0.49	6,180	9,270
Ash, commercial white	200	10.2	.60	6,510	9,760
Basswood	200	9.2	.42	6,880	10,320
Beech	120	8.6	.67	13,000	19,500
Birch, yellow	200	8.5	.67	13,210	19,820
Cedar, Spanish	115	13.3	.41	5,200	7,800
Cherry[4]	115	9.1	.56	8,460	12,690
Chestnut	40	11.7	.43	4,430	6,640
Cottonwood[5]	120	8.8	.46	7,280	10,920
Cypress, southern	113	8.0	.45	6,160	9,240
Douglas fir[6]	200	8.6	.48	6,180	9,270
Elm, rock	65	9.4	.62	8,440	12,660
Elm, American (soft)	160	8.9	.52	5,860	8,790
Fir, true[7]	24	8.5	.40	5,670	8,510
Gum[8]	35	10.6	.54	6,960	10,440
Gum, tupelo	80	10.3	.50	6,260	9,390
Gum, red	182	8.7	.54	7,850	11,780
Hackberry	80	10.2	.54	6,920	10,380
Hemlock, western (West Coast)	119	9.7	.47	6,800	10,200
Magnolia[9]	80	8.8	.58	9,220	13,830
"Mahogany, African,"[10]	20	12.7	.52	5,370	8,060
"Mahogany, Philippine"[11]	25	10.7	.53	10,670	16,000
Mahogany, true	35	11.4	.48	6,390	9,580
Maple, soft[12]	120	8.9	.57	8,180	12,270
Maple, hard[13]	192	8.0	.68	10,190	15,290
Oak, commercial red	115	9.3	.59	5,480	8,220
Oak, commercial white	195	9.5	.64	6,730	10,100
Pine, sugar	110	8.0	.42	5,530	8,300
Pine, northern white	40	5.4	.42	5,720	8,580
Redwood	105	9.7	.42	4,770	7,160
Spruce, Sitka	121	8.3	.42	5,650	8,480
Sycamore	163	9.2	.56	8,030	12,040
Walnut, black	110	9.1	.59	8,250	12,380
Yellow poplar	155	9.4	.50	7,390	11,080
Yucca species	33	7.3	.49	2,210	3,320

NOTE: *Sample computation:* To obtain the tensile strength of 3-ply wood consisting of two 1/20-inch birch faces and a 1/16-inch basswood core: Parallel to face grain $= 2 \times 1/20 \times 19{,}820 =$ 1982 pounds per inch of width; perpendicular to face grain $= 1 \times 1/16 \times 10{,}320 = 645$ pounds per inch of width. This computation neglects the tensile strength of the ply or plies perpendicular to the grain, which is comparatively small, and the results are therefore slightly in error.

[1] Specific gravity based on oven-dry weight and volume at test.
[2] Based on total cross-sectional area.
[3] Based on assumption that center-ply carries no load. Data based on tests of three-ply panels with all plies in any one panel same thickness and species.
[4] Probably black cherry.
[5] Probably Eastern cottonwood.
[6] Coast region.
[7] Probably white fir.
[8] Probably black gum.
[9] Probably evergreen magnolia.
[10] Probably Khaya species.
[11] Probably tanguile.
[12] Probably silver maple.
[13] Sugar or black.

Table IX. 19

Strength of Various Species of Three-ply Panels

(Data by U. S. Forest Products Laboratory)

NOTE: All plies in any one panel were of the same thickness and of the same species—grain of successive plies at right angles. In most cases 8 thicknesses of plywood, ranging from $^3/_{30}$ to $^3/_8$ inch, were tested

Species	*Average Specific Gravity of Plywood, Based on Oven-dry Weight and Volume at Test*	*Average Moisture*	*Column Bending*					
			Column-bending Modulus				*Modulus of Elasticity*	
			Parallel[1]		*Perpendicular*[1]		*Parallel*	*Perpendicular*
		Per cent	*Number of Tests*	*Pounds per Square Inch*	*Number of Tests*	*Pounds per Square Inch*	*1000 Pounds per Square Inch*	
Ash, black	0.49	9.1	120	7,760	120	1,770	1,070	96
Ash, commercial white	.60	10.2	200	9,930	200	2,620	1,420	143
Basswood	.42	9.2	200	7,120	200	1,670	1,210	85
Beech	.67	8.6	120	15,390	120	2,950	2,150	167
Birch, yellow	.67	8.5	195	16,000	200	3,200	2,260	197
Cedar, Spanish	.41	13.3	115	6,460	115	1,480	1,030	84
Cherry[3]	.56	9.1	115	12,260	115	2,620	1,630	152
Chestnut	.43	11.7	40	5,160	40	1,110	740	75
Cottonwood[4]	.46	8.8	120	8,460	120	1,870	1,440	109
Cypress, southern	.45	8.0	113	8,890	113	1,850	1,220	95
Douglas fir[5]	.48	8.6	170	9,340	200	1,940	1,530	126
Elm, rock	.62	9.4	65	12,710	65	2,500	1,980	136
Elm, American (soft)	.52	8.9	160	8,680	160	1,970	1,220	109
Fir, true[6]	.40	8.5	24	9,200	24	1,811	1,580	100
Gum[7]	.54	10.6	40	8,090	40	1,920	1,280	113
Gum, tupelo	.50	10.3	80	7,760	80	1,580	1,300	111
Gum, red	.54	8.7	182	9,970	182	2,070	1,590	120
Hackberry	.54	10.2	80	8,100	80	1,880	1,150	99
Hemlock, western (West Coast)	.47	9.7	119	9,250	119	1,960	1,580	112
Magnolia[8]	.58	8.8	80	10,830	80	2,600	1,700	138
"Mahogany, African"[9]	.52	12.7	20	8,070	20	2,000	1,260	144
"Mahogany, Philippine"[10]	.53	10.7	25	10,160	25	2,310	1,820	169
Mahogany, true	.48	11.4	35	8,500	35	1,940	1,250	117
Maple, soft[11]	.57	8.9	120	11,540	120	2,420	1,750	145
Maple, hard[12]	68	8.0	202	15,600	202	3,340	2,110	189
Oak, commercial red	.59	9.3	115	8,500	115	2,070	1,290	120
Oak, commercial white	.64	9.5	195	10,490	195	2,310	1,340	118
Pine, sugar	.42	9.4	65	8,050	70	1,670	1,310	90
Pine, northern white	.42	5.4	40	10,130	40	2,050	1,570	111
Redwood	.42	9.7	105	8,230	105	1,550	1,180	108
Spruce, Sitka	.42	8.3	121	7,710	121	1,690	1,370	105
Sycamore	.56	9.2	163	11,040	163	2,340	1,630	130
Walnut, black	.59	9.1	110	12,660	110	2,770	1,740	141
Yellow poplar	.50	9.4	165	8,860	165	1,920	1,540	115
Yucca species	.49	7.3	33	2,960	33	900	560	44

NOTE: In some of the species listed above the tests are rather limited in number. Since there is considerable variation in the strength of wood, further tests on additional material would be expected to modify the values appreciably in some cases.

[1] Parallel and perpendicular refer to the direction of the grain of the faces relative to the direction of the application of the force.

[2] The relative splitting resistance of the various panels tested depends largely on the holding strength of glue.

[3] Probably black cherry.

[4] Probably eastern cottonwood.

[5] Coast region.

[6] Probably white fir.

[7] Probably black gum.

[8] Probably evergreen magnolia.

[9] Probably Khaya sp.

[10] Probably tanguile.

[11] Probably silver maple.

[12] Sugar or black maple.

(Continued on next page)

Table IX. 19—(*Continued*)
Strength of Various Species of Three-ply Panels
(Data by U. S. Forest Products Laboratory)

Species	Average Specific Gravity of Plywood, Based on Oven-dry Weight and Volume	Average Moisture	Tensile-Strength				Splitting Resistance	
			Parallel		Perpendicular			
		Per Cent	Number of Tests	Pounds per Square Inch	Number of Tests	Pounds per Square Inch	Number of Tests	Per Cent of birch [2]
Ash, black	0.49	9.1	120	6,180	120	3,940	240	73
Ash, commercial white	.60	10.2	200	6,510	200	4,350	400	71
Basswood	.42	9.2	200	6,880	200	4,300	400	63
Beech	.67	8.6	120	13,000	120	7,290	240	94
Birch, yellow	.67	8.5	200	13,210	200	7,700	400	100
Cedar, Spanish	.41	13.3	115	5,200	115	3,340	230	60
Cherry [3]	.56	9.1	115	8,460	115	5,920	230	80
Chestnut	43	11.7	40	4,430	40	2,600	80	74
Cottonwood[4]	46	8.8	120	7,280	120	4,240	240	85
Cypress, southern	.45	8.0	113	6,160	113	3,980	148	49
Douglas fir[5]	.48	8.6	200	6,180	200	3,910	374	63
Elm, rock	.62	9.4	65	8,440	65	5,500	130	99
Elm, American (soft)	.52	8.9	160	5,860	160	3,990	320	75
Fir, true[6]	.40	8.5	24	5,670	24	3,770	48	60
Gum[7]	.54	10.6	35	6,960	35	4,320	70	55
Gum, tupelo	.50	10.3	80	6,260	80	3,760	160	60
Gum, red	.54	8.7	182	7,850	182	4,930	364	80
Hackberry	.54	10.2	80	6,920	80	4,020	160	84
Hemlock, western (West Coast)	.47	9.7	119	6,800	119	4,580	238	63
Magnolia[8]	.58	8.8	80	9,220	80	5,730	120	85
"Mahogany, African"[9]	.52	12.7	20	5,370	20	3,770	.....	.....
"Mahogany, Philippine"[10]	.53	10.7	25	10,670	25	5,990	50	90
Mahogany, true	.48	11.4	35	6,390	35	3,780	.....	.....
Maple, soft[11]	.57	8.9	120	8,180	120	5,380	240	106
Maple, hard[12]	.68	8.0	192	10,190	202	6,530	404	114
Oak, commercial red	.59	9.3	115	5,480	115	3,610	230	70
Oak, commercial white	.64	9.5	195	6,730	195	4,200	390	85
Pine, sugar	.42	9.4	70	5,430	70	3,690	140	47
Pine, northern white	.42	5.4	40	5,720	40	3,340	80	31
Redwood	.42	9.7	105	4,770	105	2,960	210	48
Spruce, Sitka	.42	8.3	121	5,650	121	3,410	224	78
Sycamore	.56	9.2	163	8,030	163	5,220	326	77
Walnut, black	.59	9.1	110	8,250	110	5,260	220	77
Yellow poplar	.50	9.4	155	7,390	165	4,720	330	51
Yucca species	.49	7.3	33	2,210	33	1,700	66	14

For reference marks, see footnote at bottom of first page of table.

Table IX. 20

Comparison of Strength of Three-, Five-, Seven-, and Nine-ply Yellow Birch Plywood

All plies of same thickness in any one panel

(Data by U. S. Forest Products Laboratory)

Number of Plies	*Average Specific Gravity*[1]	*Average Moisture*	*Range of Total Panel Thicknesses*	*Number of Tests*	*Column-bending Modulus*		*Tension*		*Ratio of Average Splitting Resistance to Three-ply Birch of Same Thickness*
					Parallel[2]	*Perpendicular*[2]	*Parallel*	*Perpendicular*	
		Per Cent	*Inch*		*Lb. per Sq. In.*	*Lb. per Sq. In.*	*Lb. per Sq. In.*	*Lb. per Sq. In.*	*Per Cent*
Three ply...	0.67	8.5	3/30 to 3/6	195	16,000	3,200	13,210	7,700	100
Five ply....	.66	12.3	5/48 to 5/10	60	11,780	5,320	12,700	8,680	183
Seven ply...	.67	12.7	7/48 to 7/12	55	11,490	6,190	11,860	9,150	235
Nine ply...	.70	18.9	9/48 to 9/16	25	8,150	5,830	10,140	8,140	342

[1] Specific gravity based on oven-dry weight and volume at test.

[2] Parallel and perpendicular refer to direction of grain of faces relative to direction of application of force.

Table IX. 21

Comparison of Strength of Three-ply Wood

Cores of high density with cores of low density of the same thickness; each ply 1/20 inch thick

(Number of tests very limited. Results tabulated will probably be changed by further tests)

Species			*Number of Tests*	*Plywood Thickness*	*Per Cent Moisture at Test*	*Specific Gravity, Based on Oven-dry Weight and Volume at Test*	*Column-bending Modulus in Pounds per Square Inch*		*Tension in Pounds per Square Inch*		*Maximum Unit Load in Pounds per Square Inch, 5 by 12 Inch Specimen Tested as a Column*	
Face	*Core*	*Face*					*Parallel**	*Perpendicular**	*Parallel**	*Perpendicular**	*Parallel**	*Perpendicular**
				In.								
Birch..	Birch..	Birch..	30	0.15	9.4	0.68	14,200	3,170	11,900	7,290	258	21
Birch..	Basswood..	Birch..	10	.14	8.2	.61	15,200	1,600	12,900	3,800	250	12
Sugar maple.	Sugar maple.	Sugar maple.	33	.15	6.9	.69	16,100	3,210	9,910	6,540	265	45
Sugar maple.	Basswood..	Sugar maple.	5	.15	7.0	.62	17,700	2,600	12,000	3,700	247	15
Red gum..	Red gum..	Red gum..	20	.14	9.5	.55	9,550	2,060	8,410	4,720	193	35
Red gum...	Basswood..	Red gum..	5	.15	8.3	.44	7,200	1,400	4,900	3,000	115	11
Red gum...	Yellow poplar.	Red gum..	5	.14	6.5	.51	10,100	......	6,200	4,500	149	17

* Directions refer to direction of application of the force relative to the grain of the faces.

Table IX. 22
Comparative Strengths of Five Species of Sawed, Sliced, and Rotary-cut Plywood

Each panel composed of 3 plies of 1/16-inch veneer; grain of successive plies at right angles; casein glue used

(Data by U. S. Forest Products Laboratory)

Species	*Method of Manufacture*	*Average panel Thickness Inches*	*Specific Gravity* †	*Per Cent Moisture*	*Column-bending Modulus*			
					*Parallel**		*Perpendicular**	
					Number of Tests	*Pounds per Square Inch*	*Number of Tests*	*Pounds per Square Inch*
Ash, commercial white...	Sawed.....	0.206	0.55	11.4	10	8,220	10	2,160
Do................	Sliced......	.183	.56	10.9	10	9,670	10	1,940
Do................	Rotary cut..	.193	.52	12.0	10	7,180	10	1,810
Birch................	Sawed.....	.194	.65	10.1	8	10,520	8	2,660
Do................	Sliced......	.169	.65	9.4	9	9,670	9	1,760
Do................	Rotary cut..	.182	.61	10.3	10	11,330	10	2,340
Mahogany, African.....	Sawed......	.212	.53	10.0	10	7,930	10	2,000
Do................	Sliced......	.170	.52	11.0	6	8,360	6	2,110
Maple, sugar...........	Sawed......	.196	.67	11.2	9	13,670	9	2,750
Do................	Sliced......	.176	.67	10.2	10	13,400	10	2,480
Do................	Rotary cut..	.134	.67	10.8	10	12,650	10	2,300
Poplar, yellow..........	Sawed.....	.194	.51	8.7	10	8,630	10	1,950
Do................	Sliced......	.172	.50	8.5	10	9,060	10	1,790
Do................	Rotary cut..	.179	.50	8.8	10	7,710	10	1,580

Species	*Method of Manufacture*	*Tensile Strength*				*Splitting Resistance*		
		*Parallel**		*Perpendicular**				
		Number of Tests	*Pounds per Square Inch*	*Number of Tests*	*Pounds per Square Inch*	*Number of Tests*	*Total Work in Splitting, Inch-pounds*	*Splitting Modulus Inch-pounds per Inch*
Ash, commercial white.	Sawed.....	10	6,810	10	4,310	20	910	4,400
Do..............	Sliced.....	10	7,040	10	4,770	20	690	3,790
Do..............	Rotary cut	10	4,290	10	3,180	20	650	3,350
Birch................	Sawed.....	8	8,600	8	6,590	16	1,620	8,360
Do..............	Sliced.....	9	9,230	9	5,760	18	1,460	8,660
Do..............	Rotary cut	10	11,350	10	5,970	20	1,360	7,460
Mahogany, African...	Sawed.....	10	7,220	10	4,200	20	1,770	8,380
Do..............	Sliced.....	6	6,690	6	4,270	72	1,180	6,920
Maple, Sugar.........	Sawed.....	9	11,810	9	6,810	18	1,230	6,250
Do..............	Sliced.....	10	11,340	10	6,770	20	1,110	6,290
Do..............	Rotary cut	10	10,140	10	5,750	20	1,250	6,450
Poplar, yellow........	Sawed.....	10	9,610	10	4,780	20	1,150	5,960
Do..............	Sliced.....	10	8,140	10	4,720	20	890	5,180
Do..............	Rotary cut	10	8,540	10	4,180	20	805	4,500

* Parallel and perpendicular refer to direction of grain of faces relative to direction of application of force.

† Specific gravity based on oven-dry weight and volume at test.

Table IX. 23
Weights of Veneer

(In ounces per square foot of single-ply, oven-dry; veneer thicknesses in inches)

Species	Specific Gravity Oven-dry Based on Volume Air-dry	Air-dry Moisture Content, Per Cent	Thickness in Inches							
			1/100	1/80	1/64	1/60	1/55	1/48	1/40	1/32
Ash, black	0.50	10.4	0.42	0.52	0.65	0.69	0.76	0.87	1.04	1.30
Ash, commercial white	.58	8.9	.48	.60	.75	.80	.88	1.00	1.21	1.51
Basswood	.38	8.4	.32	.40	.49	.53	.58	.66	.79	.99
Beech	.63	11.2	.52	.66	.82	.87	.95	1.09	1.31	1.64
Birch, yellow	.63	9.6	.52	.66	.82	.87	.95	1.09	1.31	1.64
Butternut	.39	7.6	.32	.41	.51	.54	.59	.68	.81	1.02
Cedar, Spanish	.37	7.3	.31	.38	.48	.51	.56	.64	.77	.96
Cherry, black	.51	9.2	.42	.53	.66	.71	.77	.88	1.06	1.33
Chestnut	.44	8.6	.37	.46	.57	.61	.67	.76	.92	1.14
Cottonwood (common)	.43	4.7	.36	.45	.56	.60	.65	.75	.90	1.12
Cypress, bald	.44	9.0	.37	.46	.57	.61	.67	.76	.92	1.14
Douglas fir (coast type)	.51	6.2	.42	.53	.66	.71	.77	.88	1.06	1.33
Douglas fir (mountain type)	.44	9.4	.37	.46	.57	.61	.67	.76	.92	1.14
Elm, white	.51	8.8	.42	.53	.66	.71	.77	.88	1.06	1.33
Gum, black	.52	7.2	.43	.54	.68	.72	.79	.90	1.08	1.35
Gum, cotton	.52	6.1	.43	.54	.68	.72	.79	.90	1.08	1.35
Gum, red	.49	11.3	.41	.51	.64	.68	.74	.85	1.02	1.28
Hackberry	.54	9.2	.45	.56	.70	.75	.82	.94	1.12	1.40
Hemlock, western	.42	8.6	.35	.44	.55	.58	.64	.73	.87	1.09
Magnolia (evergreen)	.51	8.8	.42	.53	.66	.71	.77	.88	1.06	1.33
Mahogany (Central Amer.)	.49	7.9	.41	.51	.64	.68	.74	.85	1.02	1.28
Mahogany (African)	.46	8.0	.38	.48	.60	.64	.70	.80	.96	1.19
Maple (silver)	.48	8.2	.40	.50	.62	.67	.73	.83	1.00	1.25
Maple (sugar)	.62	10.5	.52	.65	.81	.86	.94	1.08	1.29	1.61
Oak, commercial red	.64	10.7	.53	.67	.83	.89	.97	1.11	1.33	1.66
Oak, commercial white	.68	11.0	.57	.71	.88	.94	1.03	1.18	1.41	1.77
Pine, long-leaf	.66	9.2	.55	.69	.86	.92	1.00	1.15	1.37	1.72
Pine, sugar	.37	11.4	.31	.38	.48	.51	.56	.64	.77	.96
Pine, short-leaf	.54	11.0	.45	.56	.70	.75	.82	.94	1.12	1.40
Pine, western yellow	.41	10.8	.34	.43	.53	.57	.62	.71	.85	1.07
Pine, white	.39	9.9	.32	.41	.51	.54	.59	.68	.81	1.02
Poplar, yellow	.41	6.1	.34	.43	.53	.57	.62	.71	.85	1.07
Spruce, Sitka	.38	8.9	.32	.40	.49	.53	.58	.66	.79	.99
Sycamore	.50	9.2	.42	.52	.65	.69	.76	.87	1.04	1.30
Tanguile (Philippine mahogany)	.54	11.8	.45	.56	.70	.75	.82	.94	1.12	1.40
Walnut, black	.57	4.8	.47	.59	.74	.79	.86	.99	1.19	1.48

Weight of glue per square foot: Blood albumin, about 0.3 ounce; Certus, about 0.4 ounce.

The weight of wood is quite variable, so that while the table given represents the average weights of material tested, large variations from these figures may be expected in individual pieces of veneer.

The example presented is slightly in error through neglecting the change in volume between the moisture content at 12 per cent and the moisture listed in the table.

Table IX. 23—(*Continued*)
Weights of Veneer

(In ounces per square foot of single-ply, oven dry; veneer thicknesses in inches)

Species	*Thickness in Inches*									
	1/28	1/24	1/20	1/16	1/12	1/10	1/8	1/6	3/16	1/4
Ash, black	1.49	1.74	2.08	2.60	3.47	4.16	5.20	6.94	7.81	10.41
Ash, commercial white	1.72	2.01	2.41	3.02	4.02	4.82	6.04	8.05	9.05	12.06
Basswood	1.13	1.32	1.58	1.98	2.64	3.16	3.96	5.28	5.94	7.92
Beech	1.87	2.19	2.62	3.28	4.37	5.24	6.56	8.74	9.84	13.12
Birch, yellow	1.87	2.19	2.62	3.28	4.37	5.24	6.56	8.74	9.84	13.12
Butternut	1.16	1.35	1.62	2.03	2.71	3.25	4.06	5.42	6.09	8.12
Cedar, Spanish	1.10	1.28	1.54	1.92	2.57	3.08	3.85	5.13	5.78	7.70
Cherry, black	1.52	1.77	2.12	2.65	3.54	4.25	5.31	7.08	7.96	10.62
Chestnut	1.31	1.53	1.83	2.29	3.05	3.66	4.58	6.10	6.87	9.16
Cottonwood (common)	1.28	1.49	1.79	2.24	2.98	3.58	4.47	5.97	6.71	8.96
Cypress, bald	1.31	1.53	1.83	2.29	3.05	3.66	4.58	6.10	6.87	9.16
Douglas fir (coast type)	1.52	1.77	2.12	2.65	3.54	4.25	5.31	7.08	7.96	10.62
Douglas fir (mountain type)	1.31	1.53	1.83	2.29	3.05	3.66	4.58	6.10	6.87	9.16
Elm, white	1.52	1.77	2.12	2.65	3.54	4.25	5.31	7.08	7.96	10.62
Gum, black	1.55	1.80	2.17	2.71	3.61	4.35	5.42	7.32	8.12	10.82
Gum, cotton	1.55	1.80	2.17	2.71	3.61	4.35	5.42	7.32	8.12	10.82
Gum, red	1.46	1.70	2.04	2.55	3.40	4.08	5.10	6.80	7.66	10.20
Hackberry	1.61	1.87	2.25	2.81	3.75	4.49	5.62	7.49	8.43	11.24
Hemlock, western	1.25	1.46	1.75	2.18	2.91	3.50	4.37	5.83	6.56	8.74
Magnolia (evergreen)	1.52	1.77	2.12	2.65	3.54	4.25	5.31	7.08	7.96	10.62
Mahogany (Central Amer.)	1.46	1.70	2.04	2.55	3.40	4.08	5.10	6.80	7.66	10.20
Mahogany (African)	1.37	1.59	1.91	2.39	3.19	3.83	4.78	6.38	7.17	9.57
Maple (silver)	1.43	1.67	2.00	2.50	3.33	4.00	5.00	6.66	7.50	7.00
Maple (sugar)	1.85	2.15	2.58	3.23	4.30	5.16	6.46	8.60	9.69	12.91
Oak, commercial red	1.90	2.22	2.66	3.33	4.44	5.32	6.66	8.88	9.99	13.32
Oak, commercial white	2.02	2.36	2.83	3.54	4.72	5.66	7.08	9.43	10.61	14.16
Pine, long-leaf	1.96	2.29	2.75	3.44	4.58	5.50	6.88	9.16	10.32	13.75
Pine, sugar	1.10	1.28	1.54	1.92	2.57	3.08	3.85	5.13	5.78	7.70
Pine, short-leaf	1.61	1.87	2.25	2.81	3.75	4.49	5.62	7.49	8.43	11.24
Pine, western yellow	1.22	1.42	1.71	2.13	2.84	3.41	4.27	5.69	6.40	8.54
Pine, white	1.16	1.35	1.62	2.03	2.71	3.25	4.06	5.42	6.09	8.12
Poplar, yellow	1.22	1.42	1.71	2.13	2.84	3.41	4.27	5.69	6.40	8.54
Spruce, Sitka	1.13	1.32	1.58	1.98	2.64	3.16	3.96	5.28	5.94	7.92
Sycamore	1.49	1.74	2.08	2.60	3.47	4.16	5.20	6.94	7.81	10.41
Tanguile (Philippine mahog.)	1.61	1.87	2.25	2.81	3.75	4.49	5.62	7.49	8.43	11.24
Walnut, black	1.70	1.98	2.37	2.97	3.96	4.75	5.94	7.92	8.91	11.87

Above weight determinations by U. S. Forest Products Laboratory.

Example: To get the weight of a square foot of 5-ply wood consisting of 1 ply of 1/12-inch basswood, 2 plies of 1/16-inch basswood, and 2 plies of 1/20-inch yellow birch for faces, at 12 per cent moisture, glued with Certus glue:

$$\text{Weight} = (1\times 2.64+2\times 1.98+2\times 2.62)\ 1.12+4\times 0.4 = 14.68 \text{ ounces}$$

Table IX. 24

Thickness Factors for Veneer, Compared to Birch

Giving: (1) Veneer thickness for the same total bending strength as birch; (2) veneer thickness for the same weight as birch.

(Data by U. S. Forest Products Laboratory)

Species	D. Average Specific Gravity of Species[1] Based on Oven-dry Weight and Air-dry Volume	Specific Gravity of Glued Plywood as Tested	Per Cent Moisture of Plywood as Tested	S. Per Cent Unit Bending Strength Compared with Birch[2]	K Thickness Factor for the Same Total Bending Strength as Birch $\sqrt{\frac{100}{S}}$	K_w Thickness Factor for the Same Weight as Birch, $\frac{0.63}{D}$
Ash, black	0.50	0.49	9.1	52	1.39	1.26
Ash, commercial white	.58	.60	10.2	72	1.18	1.09
Basswood	.38	.42	9.2	48	1.44	1.66
Beech	.63	.67	8.6	94	1.03	1.00
Birch, yellow	.63	.67	8.5	100	1.00	1.00
Cedar, Spanish	[a].34	.41	13.3	43	1.52	1.85
Cherry[b]	.51	.56	9.1	80	1.12	1.24
Chestnut	.44	.43	11.7	34	1.72	1.43
Cottonwood	.43	.46	8.8	56	1.34	1.47
Cypress, bald	.44	.47	10.3	53	1.37	1.43
Elm, cork	.66	.62	9.4	78	1.13	.95
Elm, white	.51	.52	8.9	58	1.31	1.24
Fir, Douglas	[c].51	.49	8.7	60	1.29	1.24
Gum, black	.52	.54	10.6	56	1.34	1.21
Gum, cotton	.52	.50	10.3	48	1.44	1.21
Gum, red	.49	.54	8.7	64	1.25	1.29
Hackberry	.54	.54	10.2	55	1.35	1.17
Hemlock, western	.42	.47	9.7	60	1.29	1.50
Magnolia	.51	.58	9.9	67	1.22	1.24
Mahogany, African	[a].46	.52	12.7	56	1.34	1.37
Mahogany, Philippine[d]	[a].57	.53	10.7	68	1.21	1.10
Mahogany, true	[a].49	.48	11.4	57	1.32	1.29
Maple, soft[e]	.48	.57	8.9	74	1.16	1.31
Maple, sugar	.62	.68	8.0	100	1.00	1.02
Oak, commercial red	.63	.59	9.3	59	1.30	1.00
Oak, commercial white	.69	.64	9.5	69	1.20	.91
Pine, white	.39	.43	10.2	52	1.38	1.61
Poplar, yellow	.41	.50	9.4	58	1.31	1.54
Redwood	[a].36	.41	11.2	49	1.43	1.75
Sycamore	.50	.56	9.2	71	1.09	1.26
Spruce, Sitka	.38	.43	8.4	50	1.41	1.66
Walnut, black	.57	.59	9.1	83	1.10	1.10

[1] Taken from Bulletin 556 of the U. S. Dept. of Agriculture.

[2] Average of the column-bending moduli parallel and perpendicular to grain compared to birch.

[a] Based on subsequent tests. [b] Probably black cherry. [c] Coast type Douglas fir.

[d] Probably tanguile. [e] Probably silver maple.

SECTION TEN

GRADING RULES

The producers of veneer and plywood in the United States are widely separated geographically and deal in softwoods and hardwoods of a number of species of both plain and figured varieties. They make products that vary all the way from the humble box shook, that merely protects its contents from rough usage, to the electric organ, that requires most unusual precision in its construction.

It would be well nigh impossible to collect all these diverse interests together in a single trade association, or to devise a usable set of grade rules that would embrace such a wide range of products with such a multitude of requirements both as to appearance and performance.

There are, however, several unrelated trade associations, intended primarily for trade promotion, but including in their activities the development and regulation of grading and inspection.

It happens that grade rules and their interpretation are constantly in the process of improvement and readjustment, to meet current conditions as they may change from time to time. Hence, it is inadvisable to attempt to reproduce any grade rules in this handbook, except in abstracted form for general use. Readers are respectfully referred to the current edition of the grade rules of each group or association, for such exact information as may be required in classifying products, in grading and inspection rules, or in purchase arrangements.

There are a number of **Commercial Standards,** promulgated by the National Bureau of Standards, with the co-operation of each industry. These describe the conditions under which trade negotiations may be conducted between purchasers and sellers of veneer and plywood products, provided proper stipulations are made as to the source of the standards employed.

The names and addresses of the principal veneer and plywood groups and associations are given, and these should be consulted. Under these groups are also listed any applicable Commercial Standards publications of the United States Government.

Certain trade customs have developed in the warehousing of different grades of stock plywood that may be found convenient for plywood purchasers. The literature of the United States Plywood Corporation should be consulted.

Commercial Veneer

The Veneer Association, 616 South Michigan Avenue, Chicago, Illinois.

National Hardwood Lumber Association, 59 East Van Buren Street, Chicago, Illinois.

The membership of the Veneer Association comprises producers of veneers, rather than plywood, both commercial (unfigured veneer) and face veneer. Since its members deal almost exclusively in the hardwood veneers, arrangements have been made to include these veneer grade rules in the annual rule book of the National Hardwood Lumber Association. The current grade rules for veneer are included in the booklet that is issued on January 1st of each year, and can be obtained by remitting 25 cents to the National Hardwood Lumber Association.

The more essential features of these rules can be listed briefly as follows:

1a. Veneers shall be of practically uniform standard thickness when green.

1b. All veneers shall be dried to prevent mold in shipping, and flat enough to straighten under pressure without splitting.

1c. Dimensions should be stated in the following order: thickness, width, length.

4. Dimension stock shall be cut to square to the size specified. If part pieces are permitted, 1-inch width allowance shall be made for each joint.

6. **Faces,** unselected for color, shall be free of defects, except slight splits that will close in laying; **selected faces** may be specified within this grade.

7. **Sound backs** admit certain minor defects.

8. **Reject backs** admit substantial defects, but must provide reasonable coverage.

9. **Drawer bottoms** admit small defects.

10. **Crossbanding** admits minor defects that will not show through faces, and must be 50% free of knots.

11. **Core** or center stock comes in three grades.

12. **Log run** provides for cutting the full product of the log for utilization.

13. **Sheet stock** provides standards for random widths and uniform lengths for packaging and shipping.

The above rules apply without reservations to **gum** (sweet, black, tupelo) **sycamore, cottonwood, poplar,** southern **maple,** southern **basswood, magnolia, cypress** and **yellow pine.** They apply with certain modifications to other species of veneer, and these applications are listed for the following groups:

Rotary red oak, white oak and chestnut.
Rotary ash, northern basswood, beech, birch, elm and maple.
Sawn and sliced quartered white and red oak.
Sawn and sliced plain white and red oak.
Sawn red gum.
Quartered red gum.
Sawn and sliced piano rim stock.

The official rule book should be consulted for more exact provisions.

Face Veneers

American Walnut Manufacturers Association, 616 South Michigan Avenue, Chicago, Illinois.

This Association includes manufacturers of both veneer and lumber, but limits its activities to the one species, which is all native grown.

Since walnut face veneers are sold by samples, the grade rules are principally concerned with accurate and fair sampling and classification along the following lines:

Minimum footage
Minimum width, 40 full sheets from the top
Minimum length
Guaranteed yield
Cuttings allowed to determine guaranteed yield
Minor defect allowances

Grades, from the highest down, are:

AA, A+, A
BB, B+, B
CC, C

Tabulations for the above classifications are made on:

Sliced and half-round walnut
Rotary walnut
Quarters

There is a Commercial Standard CS 64 37, issued by the National Bureau of Standards, dated December 15, 1937. Either this or the association publications should be consulted for further exact details.

Mahogany Association, 75 East Wacker Drive, Chicago, Illinois.

This Association, like the American Walnut above, includes the producers of both veneer and lumber. Genuine mahogany is practically all imported from Africa, South and Central America. Near mahogany and trees that resemble mahogany may come from other areas, but in general are less desirable than the true mahoganies. True mahogany is usually sliced, sometimes sawn, is kept in sequence in flitches and sold by sample. There are no generally recognized grading rules, and quality, size, figure and character are matters for negotiation between buyer and seller. No Commercial Standards (U. S. Bureau of Standards) are in effect. Descriptive literature is available at the above address.

Hardwood Plywood

Plywood Manufacturers Institute, 205 West Wacker Drive, Chicago, Illinois.

Southern Plywood & Veneer, Inc., Johnston Building, Charlotte, North Carolina.

Each Association operates within geographic limits and is concerned with hardwood plywood only. Neither Association provides grading rules.

Commercial Standards, CS 35 31 (Hardwood Plywood) September 1st, 1931, was promulgated by the National Bureau of Standards; and a revision is overdue.

In general, this standard specification designates grades for each layer, although that for cores and crossbanding is optional with the manufacturer, unless otherwise specified. Certain variations apply to different species. Briefly stated, the following are the approximate requirements:

	Grades	
Faces	A	Matched for uniform grain and color, with some minor blemishes permitted
	1	Matched for color, but not for grain, slightly more tolerance for blemishes
	2	Not matched for color or grain, defects permissible under certain regulations
	3	Same as reject backs

Backs	Sound	Any species permissible, not matched, minor defects allowed
	Reject	Wide tolerance for defects as long as serviceable back layer of veneer is provided
Lumber Cores	A	Tight joints, strips not over 4 inches wide, clear of defects
	1	Same, but strips not over 5 inches wide
	2	Same as 1, but certain defects and repairs permissible
	3	Same as 2, but only edges need be clear of defects to 1½ inch depth
Veneer Cores	A	One piece without open defects
	1	Two or more pieces of uniform thickness, without open joints
	2	Admitting wide tolerance on defects
Cross-banding	A	One piece without open defects
	1	Two or more pieces, jointed and taped, without open defects
	2	Requires sufficient soundness not to impair face veneer

Due to the date of this standard, as well as to the changes that have occurred in the industry, it is advised that those interested confer with the Bureau of Standards, and have definite understandings in any sales or purchase negotiations.

Douglas Fir Plywood

Douglas Fir Plywood Association, Tacoma Building, Tacoma, Washington.

The membership of this Association consists of manufacturers of veneer and plywood of Douglas fir. The single-ply veneer is not an article of commerce, as each plywood manufacturer cuts his own supply. The Association has a comprehensive line of promotional and technical literature that is closely co-ordinated with Commercial Standards CS 45 38, issued by the National Bureau of Standards in 1938.

The makers of Douglas fir plywood employ three grades of water-resistant adhesives, the tests for which are fully described on pages 334-5.

The grade rules for Douglas fir can be stated briefly as follows:

Good Two Sides (G-2-S)—This grade is intended for natural or light stain finishes. Both faces are clear and 100% heartwood of a yellow or pinkish color.

Good One Side (G-1-S)—One face is the same as that described under Good Two Sides grade, while the opposite face is the same as the Sound Two Sides grade described below.

Sound Two Sides (SO-2-S)—This grade presents a smooth, sound surface on both sides suitable for painting. The faces may be of one or more pieces of firm, smoothly cut veneer. If of more than one piece, they will be well joined and reasonably matched for grain and color at the joints. Sap and natural discoloration are considered no defect.

Wallboard (Plywall)—The face side is the same as described under Sound Two Sides. The opposite side contains defects in number and size that will not affect the strength or serviceability of the panel.

Sheathing (Plyscord)—Both sides of this 5/16-inch, ⅜-inch and ⅝-inch unsanded plywood contain defects which will not seriously affect strength or serviceability, but one face is made tight by patching.

Concrete Form Material (Plyform)—(Made in standard panel dimensions with special highly water-resistant glue). ⅝-inch thickness is recommended for most form jobs, but ½, 9/16, 11/16 and ¾-inch panels are stocked in standard panel widths and lengths. Both faces are carefully selected and are similar to those in Sound Two Sides panels, but must be at least ⅛ inch thick before sanding. Panels are distinctively edge-sealed and mill-oiled. Panels ¼ inch thick are available as form liners and for curved surfaces.

Exterior (EXT-DFPA)—This class of panel made in various grades and with waterproof glue is suitable for permanent exterior exposures.

Due to the possibility of changes in standard specifications, current data should be obtained from either the Association or the Bureau of Standards.

SECTION ELEVEN

TESTING FOR ADHESIVE STRENGTH

There are two methods of testing wood adhesives that are stipulated in government specifications, and are also in general use by the industry. The **plywood strip shear test** is one in which properly prepared pieces of plywood are **pulled** apart, where the entire load is placed on the contact surfaces of the adhesive. These plywood strip shear tests are made regularly on normal, dry plywood, and on plywood soaked in water at room temperature for various intervals of time. Similar tests are sometimes required after immersing the samples in boiling water for considerable periods, a severe accelerative test. The effect of continuous weather exposure, usually in a warm humid climate like Florida, can also be measured by the same type of test.

The **block shear test** is a method of **pushing** apart two blocks of solid wood, where the load is similarly applied. This test is usually made on normal, dry blocks only.

As the strength factors derived from these two methods are quite different, it is important to distinguish between them in considering strength evaluation. In the case of the **plywood strip shear test,** the center layer of veneer is cross laid, and this is usually the weaker and shears **across** the grain. Ultimate strengths of the order of 250-500 pounds per square inch are to be expected in dry breaks. In the **block shear test** the grain of the wood is parallel in the joined faces, so that any rupture is **along** the grain. Breaks of the order of 2000-2800 pounds per square inch are customary on dry maple blocks.

Both tests can be made in standard testing machines, with the use of simple supplementary standard fixtures that will be illustrated and described.

In all adhesive test procedures it is important to permit the wood or plywood to age or become normal, as to temperature and moisture content, before starting the preparation of test samples. It is also essential to allow the adhesive to develop its approximate maximum strength, usually a matter of four to eight days.

Preliminary Testing

It is a common custom among plywood operators to make a rough and ready knife test on plywood, immediately after the release of pressure. This method has a practical significance, but frequently is wrongly interpreted. In the case of hot-pressed plywood, at the time of removal from the press, the surfaces are over-dry and the wood brash and brittle. Poplar will always show far more wood rupture than birch under like conditions. In the case of slanting grain in the veneer, a break may not show true adhesive strength. If the outside veneer is very hard, like maple, and is also thick and straight grained, it may exert a tremendous leverage on any adhesive joint.

It is obvious that any such premature test, before the wood or plywood has aged and become normal, and the adhesive strength is fully developed, must be considered only as preliminary. The plywood strip shear test, on thoroughly tempered plywood, is the only reliable measure of adhesive strength and durability.

Plywood Strip Shear Test, Dry and Wet

While this test is generally applicable to any plywood construction, the standard procedure requires 3-ply, 3/16-inch, straight-grained birch plywood, with center layer cross laid. The test pieces are cut down from larger plywood sheets, Fig. XI. 1, selected from various points in the sheets to give a true representation. The final test

Fig. XI. 1—Cutting plywood test samples for plywood strip shear tests.

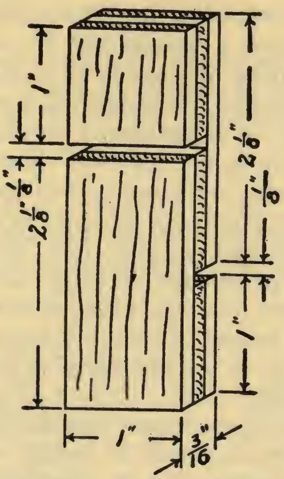

Fig. XI. 2—Slotting plywood test samples.

pieces, 3¼ inches long by 1 inch wide by 3/16 inch thick, are cross slotted as shown in Fig. XI. 2, leaving a center section, one inch square, free to resist the pull of the testing machine. It is to be noted that this pull is exerted across the grain of the central layer.

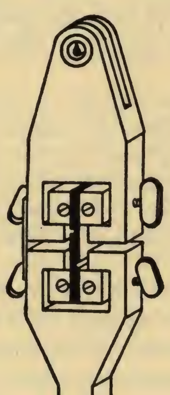

Fig. XI. 3—Fixtures for shear test on plywood strip.

These samples are mounted in the jaws of the clamp fixture shown in Fig. XI. 3, and given a tension test in any standard machine, where the rate of applying the load is from 600 to 1000 pounds per minute. Samples are tested until separation occurs, and the maximum load is recorded. It is customary to make test samples from various locations in the larger plywood sheets, selected as typical, and to test alternate adjacent samples, wet and dry. The dry tests on standard 3/16-inch birch for aircraft plywood should run 400 pounds per square inch and up, and from 250 to 350 on less dense species. A substantial percentage of wood rupture should be found in the break, except that this ratio of wood rupture is less important in the higher strength ranges. Lower breaking strength, with almost complete wood rupture, is an indication of wood weakness rather than of adhesive strength.

The wet tests, under Government specifications* for aircraft plywood, require complete immersion in boiling water for three hours, then cooling to room temperature in cold water, and wet testing.

These specifications provide a table of test strength values, grouped according to thickness, constructions, and wood densities, for both dry and wet tests.

If it becomes necessary to test plywood thicker than 3/16 inch, or with more than 3 plies, it is necessary to reduce the thickness to as nearly 3/16 inch as the construction will permit. Thicker samples exhibit, under loading in the test machine, an undesirable leverage, or eccentric effect, which prevents the proper evaluation of the strength of the joint.

The above tests apply specifically to aircraft plywood, made with a thermosetting resin adhesive. A similar method of testing is also used for cold-setting resin adhesives that are used in aircraft assembly operations. In this case the wet test is on samples submerged in cold water for 48 hours. The test values required in these assembly adhesives are on birch only, and vary from the test values mentioned above for aircraft plywood.†

It is not practical to make comparative strength tests on dry joints, as many adhesives, properly applied, will be stronger than the wood itself. The measure of durability becomes evident in wet tests, or under other accelerative exposures, where the ultimate quality of the adhesive will be clearly revealed.

Mold and Fungus Test

This was formerly required on aircraft plywood, but has been eliminated as of April 25, 1942.

* AN—NN—P—511a, April 25, 1942.
† AN—G—8, April 25, 1942.

Acidity Test

This is a new test, as of April 25, 1942, and involves a determination of the pH values of the cured resin as used for assembly purposes,* according to a procedure that is outlined at some detail.

Block Shear Test

This is a general adhesive test that is normally applied to adjacent blocks of the same species of wood, with parallel grain. It

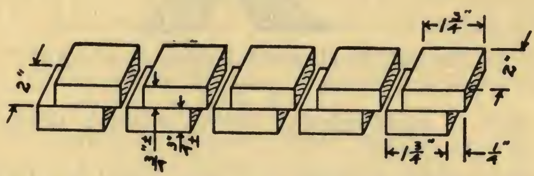

Fig. XI. 4—Preparing sample blocks for block shear tests.

may be adjusted or altered to various other types of joints and constructions. The standard procedure is on maple blocks, glued together, from strips of selected straight-grained stock, 2 inches wide by ¾ inch thick, which are sawed apart in step fashion as shown in Fig. XI. 4. This leaves an area of 2 inches by 1¾ inches, or 3 square inches, as the divisor to reduce breaking test results to a square inch basis.

Since wood has a tendency to yield gradually under pressure, and the adhesive tends to soak slowly into the wood, the combination may reduce appreciably a fixed clamp pressure. It is therefore desirable to use a continuous pressure on these maple blocks, as in a properly controlled hydraulic press, or under dead loading, as with weights or levers. Clamp pressure is less efficient in maintaining close contact between the glued surfaces.

These test specimens are tested to destruction in the fixture shown in Fig. XI. 5, where the entire load is exerted on the line of the adhesive. Carefully selected hard maple should give a result of 2800 pounds per square inch, or more when tested dry. Tests should not be made until the joint has been allowed to stand for the time necessary to develop the full strength of the adhesive.

The rate of load application should not exceed ¼ inch per minute.

This block shear test, for the present at least, is used only for cold-setting resins,* intended for aircraft assembly operations. The appli-

* AN—G—8, April 25, 1942

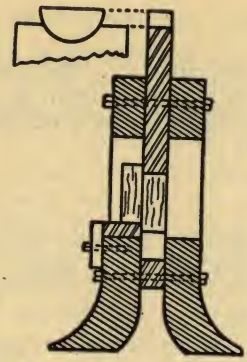

Fig. XI. 5—Fixture for block shear tests.

cation of heat to thermosetting resins in such thick members is difficult.

Due to the swelling tendency of such relatively large blocks of wood, this method is seldom employed for wet or soaking tests.

Douglas Fir Tests

Special plywood test procedures have been established by the Douglas Fir Plywood Association for this species of plywood. There are three principal classes of plywood. On **moisture-resistant** plywood it is required that sample pieces 6 inches by 6 inches be submerged continuously in water at room temperature for 4 hours, followed by drying at not over 100° F. for 20 hours. This cycle is repeated, and then the samples must not show more than 2 inches delamination anywhere along the edges.

For **exterior** plywood, tests are made with sample test pieces, cut as shown in Fig. XI. 2. These test pieces are submerged in water at room temperature for a period of 48 hours, dried for 8 hours at 145° F., followed by two cycles of 16-hour soaking and 8-hour drying, under the conditions described above. The samples are again soaked for 16 hours, and tested while wet in the fixture shown in Fig. XI. 3, with the rate of loading from 600 to 1000 pounds per minute, until failure. This is often called the 3½-cycle wet and dry test. The samples must show no less than 30%, and must average 60% average wood failure, with no delamination. No shear strength is specified. The same provisos, as on page 332, are made for thicker samples and different constructions.

There is also an adhesive classification in which no moisture resistance test is specified.

An alternate method for the 3½ cold-water cycles, described above, is boiling in water for 4 hours, dried as above for 20 hours, boiling again for 4 hours and tested wet. The test's results must be no less than those given for the 3½-cycle tests above.

TESTING FOR MOISTURE CONTENT

The proper degree of dryness, usually expressed as a percentage of **moisture content,** is an important consideration in all plywood operations. The layers of veneer and lumber must be maintained, preferably in air-conditioned rooms, at the moisture content required for the adhesive in use. Plywood will remain flat when at a normal condition of moisture content, depending on atmospheric surroundings. Progressive changes in shape are likely to occur as the moisture content departs from this normal.

To determine moisture content, small samples are cut from the veneer, lumber or plywood. These samples should be of such a shape and size as to dry out within an hour, in an oven, without charring. Samples should be free of slivers or loose particles that might drop off in handling. The sample should be weighed in its original condition, and the weight marked on sample; it is placed in the oven until a minimum weight is reached, which is, for practical purposes, bone dry; the sample is weighed again promptly on removal from the oven and the new weight is recorded below the original weight. The difference is the moisture, over bone dry, that has been removed. This can be reduced to percentages by the following formula:

$$\text{Per Cent of Moisture Content} = \frac{\text{Original Weight} - \text{Bone-dry Weight}}{\text{Bone-dry Weight}}$$

All weights should be recorded in at least two significant figures. The divisor should never be the original weight, but always the bone-dry weight, so that moisture removed is compared with dry fibre weight. See Table IX. 10, page 300-1.

The **moisture absorption** capacity is sometimes an important factor in evaluating high-density plywood for such uses as airplane propellers, where slight increases in weight might destroy a carefully established balance. Such tests are the reverse of the above, and are usually computed on the original weight, as the bone-dry weight is often difficult to determine. The formula then becomes:

$$\text{Per Cent of Moisture Absorption} = \frac{\text{Weight after Soaking} - \text{Original Weight}}{\text{Original Weight}}$$

The hygroscopic nature of wood, and its tendency to shrink and swell under moisture changes, makes this type of tests of definite importance.

TESTING ADHESIVE SPREADS

The amount of water (glue solvent) that is added when veneers are spread with adhesive and assembled into plywood has seldom been subjected to adequate control. The magnitude of the problem is indicated by Table VI. 2. This surplus water must be later removed in order that the plywood may become normal and stable. Hence, it is important to regulate the adhesive mixtures and spreading ratios to a practical optimum basis. This is a much more serious problem with the cold-setting glues, than with the hot-pressed resin adhesives. However, with the resins, excessive moisture is likely to produce the hazard of steam blisters during the hot-pressing operations. On the other hand, too little glue or adhesive may result in a "starved joint," with inadequate strength.

The importance of the accurate testing of the spread is thus quite evident. However, it is not all a mechanical process, since different amounts of adhesives are required for different types of veneer, for different species of wood, and for cold and hot setting. In general, the more porous woods need more adhesive, as does rough-cut veneer. The interval of setting or cure also requires a variation in the amount of spread: in a 10-minute cure in a hot press there is little opportunity for the adhesive to soak away from the glue line and a thin spread may be adequate; while plywood under pressure for several hours must have enough adhesive to leave an adequate supply on the glue line at the time when the delayed cure actually takes place.

The best procedure is to determine the safe and adequate spread, considering the above conditions, and prove the same by suitable samples. Then test the actual spread as follows:

Take pieces of veneer or lumber, 12 inches square, of exactly the same kind as is being spread. Weigh the same in grams and mark this as the original weight. Pass through the spreader, applying adhesive on both sides, reweigh and subtract the first weight from the second, the result being the weight (in grams) of two square feet of adhesive. This can be reduced to pounds of liquid mixture per thousand square feet of single line by the following formula:

$$S = \frac{W \times 500}{453.6} = 1.102\ W$$

W = Weight added by the adhesive, in grams, on 2 square feet.

S = Spread, in pounds, of liquid mixture, per 1000 sq. ft., single line.

453.6 = conversion factor, grams per pound avoirdupois.

For practical purposes, add 10% to the gram weight per 2 square feet to determine pounds of spread. An exact conversion table is given in Table VI. 3, page 169.

The testing scale should have a capacity of 500 grams, in gram divisions.

A general rule for approximate spreads, to be verified in each plant for different constructions and conditions, is as follows:

	Dense Woods	Porous Woods
Cold Pressed		
Resin adhesives	35-45 lb.	40-50 lb.
Other glues	70-85	80-95
Hot Pressed		
Resin adhesives	25-35	30-40

Having thus established a standard of spread, frequent verification should be made, by the above method, at least twice a day. When standards for the various constructions have been made for the plant, daily verifications are all that is necessary.

While the above method of computing the spread of adhesives, on a liquid basis, is in quite general use and is reasonably accurate over the wide range of plywood adhesives now available, there is an older method that some still prefer to use. This older basis consists in stating the pounds of dry glue required per 1000 square feet of single glue line, i.e., 25 pounds of vegetable glue, which when mixed at a ratio of one part of dry glue to two parts of water, would equal 75 pounds of mixed liquid glue. Still others specify the number of square feet of single glue line that can be spread with one pound of dry glue. In the above instance it would be 40 square feet ($1000 \div 25 = 40$). Care must be taken not to confuse these several methods of determining glue spread.

QUESTIONS

1. What are the two methods of testing for adhesive strength?
2. How do they differ in their effect on the joint?
3. How reliable are "rule of thumb" tests on hot plywood?
4. How are samples prepared for plywood strip shear tests?
5. Describe the fixture for this type of test.
6. Do tests on dry plywood give any comparative rating of the strengths of the various glues and adhesives?
7. Describe the mold and fungus test, and why is it used?
8. How does the block shear test differ from the plywood strip shear test?
9. How are block shear samples made and tested?
10. What is the Douglas fir series of tests?
11. Discuss the testing for moisture content.
12. Describe how the amount of adhesive spread is tested.

SECTION TWELVE

BIBLIOGRAPHY

The standard literature pertaining to veneer and plywood is rather meagre. Few specific books exist and much of the available information is included in publications on furniture and the allied industries, as well as in government bulletins. Useful information on recent plywood products and processes, which are the result of the reawakening of the industry since the availability of resin adhesives, is found in current periodical literature, and has not yet made its way onto the bookshelf.

The citations in the Bibliography are arranged, for more convenient reference, according to the section divisions of this handbook, hence important references may be duplicated under several sections. Under each section, references are arranged chronologically. Where available, volume, pages and date of publication are given, since some magazines start new page numbers with every issue, and in some cases use double numbering for text and advertising pages. Titles of articles, in some cases, have been made more descriptive. Anonymous (Anon.) usually indicates editorial matter or unsigned articles.

In the main, brief articles have been eliminated, except where they may mark a definite stage in the development of products or processes. In some cases articles of parallel content may be listed, or the same article listed in more than one publication, because of the possible availability of at least one of the references.

No attempt has been made to insert bibliography references in the text.

It is evident that no bibliography can hope to be complete, but the author and publisher will welcome any corrections or important omissions, for the benefit of future editions of the handbook.

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Tabular matter hitherto unavailable or difficult to obtain is provided. The excellent bibliography of magazine articles is doubly valuable because of the dearth of material available on Plywood in book form.

An organizer of the Wood Industries Division of the American Society of Mechanical Engineers, Mr. Perry has for more than thirty years been identified with Plywood Manufacturing. Technical editor of the book, *Veneers and Plywood,* he is the author of the woodworking section of Kent's *Mechanical Engineers' Handbook* and has contributed to numerous engineering, technical and trade publications. He has addressed many trade associations and industrial organizations and has lectured on woodworking subjects at Massachusetts Institute of Technology, New York State College of Forestry, Columbia University and other colleges.

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